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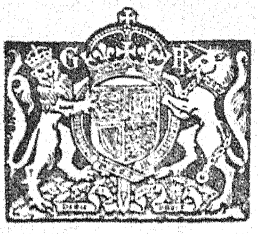

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ERRATA TO VOLUME I.

Page 81, line 11, *for* ' DESCRIPTION TYPES ' *read* ' DESCRIPTION OF TYPES '.
Page 89, line 6 from bottom, *for* ' 36 ' *read* ' 3 '.
Page 105, line 9 from bottom, *for* ' Zerophytic ' *read* ' Xerophytic '.
Page 137, last line, *for* ' p. 867 ' *read* ' p. 144 '.
Page 147, line 8, *for* ' Plants ' *read* ' Plantas '.
Page 147, line 9, *for* ' Vol. III ' *read* ' Vol. II '.
Page 198, letter press on the left of fig. 2, *for* ' $CH \times 10x$ ' *read* ' $C_H \times 10^x$ '.
Page 210, Table II, against Grand Total in Col. 7, *for* ' 25 ' *read* ' 275 '.
Page 284, line 7, *delete* p. 37.
Page 303, line 16, *for* ' 23rd February ' *read* ' 8th February '.
Page 487, line 9 from bottom, *for* ' week's ' *read* " weeks ' ".
Page 488, last line in Table XI, *for* ' Na, $SO4_2$ ' *read* ' Na_2 SO_4 '.
Page 496, Table, Col. 2, head line, *for* ' Andropogan ' *read* ' Andropogon '.
Page 502, line 30, *for* ' **4, 14** ' *read* ' **14** '.
Page 513, reference line 6, *for* ' Macqurt ' *read* ' Macquart '.
Page 518, line 10, *for* ' is more than 6 per cent. ' *read* ' is not more than 6 per acre '.
Page 518, line 16, *for* ' oil co ' *read* ' oil content '.
Page 523, line 31, *for* ' lirahs ' *read* ' liras '.
Page 568, reference, last line, *for* ' 338 ' *read* ' 538 '.
Page 593, Table VI, Col. 1, just below ' Natural cross, 1926 ' *for* ' F_3 ' *read* ' F_2 '.
Page 628, last line, *for* ' vegitative ' *read* ' vegetative '.
Page 644, Table XVI, Col. 2, last but one line, *for* ' 3·79 ' *read* ' 3·79 '.
Page 651, last line, *for* ' 467 470 ' *read* ' 467-470 '.
Page 658, Table VIII, I Sub-heading of Col. 2, *for* ' P_3 O_5 ' *read* ' P_2 O_5 '.
Page 658, Table IX, last Col., line 15, *for* ' P_3O_5 ' *read* ' P_2O_5 '.
Page 658, Table IX, last Col. line 20, *for* ' 5 ' *read* ' 50 '.
Page 659, Table, Col. 3, *for* ' P_2O5 ' *read* ' P_2O_5 '.
Page 660, Table XIV, last Col., last line, *for* ' 3 ' *read* ' 3·6 '.
Page 677, Legend of figure 4, line 2, *for* ' temparature ' *read* ' temperature '.
Page 687, Col. 4 heading, *for* ' S ' *read* ' 4 '.
Page 689, Col. 7, heading, *for* ' X & XII ' *read* ' XI & XII '.
Page 704, Table IV, Col. 4, heading, *for* ' Co_2 ' *read* ' CO_2 '.
Page 712, Table X, Col. 3, heading, *for* ' percentage ' *read* ' percentage '.
Page 714, References, 4th line from bottom, *for* ' Palladins ' *read* ' Palladin '.
Page 723, line 10, *for* ' *Elusine* ' *read* ' *Eleusine* '.

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ORIGINAL ARTICLES

STUDIES IN INDIAN OIL-SEEDS.

V. THE INHERITANCE OF CHARACTERS IN INDIAN LINSEED.

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(With Plates I-III.)

I. Introduction.

The types of Indian linseed have been studied in a previous publication [Howard and Rahman Khan, 1924] in which 123 types of this crop are described. From the economic point of view these forms fall into two divisions. The types which are native to Peninsular India possess bold seeds and a deep root-system and a somewhat procumbent habit appears in them when grown in Pusa, while the forms which grow best in the Gangetic alluvium possess small seeds, a shallow root-system and

stiff erect stems. The bold-seeded types generally possess a higher oil-content than the small-seeded types but do not grow or yield well in the Gangetic alluvium as their root-system is not adapted to the soil conditions of this tract.

The first step in the improvement of Indian linseed was the isolation of the unit species of the crop and the selection of the best oil-producing forms. This was achieved by Mrs. G. L. C. Howard and Khan Sahib Abdur Rahman Khan, and two high-yielding types of linseed, Types 12 and 121, have been distributed on a large scale and have met with great success. Type 124 is a new type, obtained recently (1926) as a selection from Type 12, and differs from the latter in possessing yellow seed of somewhat higher oil-content than that of Type 12 ; it probably arose as a mutation in this type. All these types, however, are small-seeded types adapted to the Gangetic alluvium, and an obvious further improvement would be effected if the bold-seeded character could be combined with the vegetative habit and root-system which are suited to the soils of Northern India, thus giving a bold-seeded type of good yield and high oil-content adapted to the conditions of the Gangetic plain. With this object the two best small-seeded types, Type 12 and Type 121, have been crossed with several of the bold-seeded types, and the present paper contains the results of these experiments.

The inheritance of characters in linseed has previously been investigated by Tammes [1928] and the results of our investigations generally agree with those of that author, thus the Indian types of linseed appear to be similar genetically to those investigated in Europe. Certain points of difference between our results and those of Tammes are referred to in the conclusion of this paper. Her investigations were confined to the inheritance of colour in petals, anthers and seed, but in the present study the inheritance of colour in filaments, style and stigma has also been taken into account. It has been noted by Tammes that inheritance of colour in these organs (filaments, style and stigma) has so far not been studied by any investigator, and we have also failed to find any record of such a study. The variation in the occurrence of colour in these organs, and the omission of this part of the work by previous investigators, suggested to us the advisability of paying attention to the inheritance of colour in filaments, style and stigma. Apart from what we could elucidate as to the genetical constitution of the various linseed types, our study has also pointed out the probable reason why previous investigators have excluded the study of colour inheritance in these organs. The development of colour in filaments, style and stigma is somewhat complicated on account of its dependence for full development on the amount and direction of sunlight, and on the age of the flower. Even when the genetical factors for the development of colour are present, the colour in these organs may not develop fully for want of sunlight, etc. During this study it was often found that plants which were noted as colourless in the morning developed colour after exposure to the sun's rays till noon. On this account many observations made in the beginning of this research gave inconclusive results, but in these cases when F_2 and F_3 observations were considered side by side, most

of the anomalies were solved. But, however, later on, when these difficulties were known to us, the observations on colour in filaments, style and stigma were made much later in the morning (at about 11 A.M.) and finished before 1 or 2 P.M. by which time the linseed flowers start shedding. This change in the time of observations has been of considerable assistance in getting more definite results and thereby elucidating the mechanism of inheritance of colour in these organs, and we have been able to formulate certain hypotheses which harmoniously explain the observations made in all the crosses studied.

In presenting the results of the crosses, it is proposed to give the description of the parents and first generation hybrids first and then to give the actual observations made in F_2 as regards the segregation of the various characters that have been considered in this work.

After presenting these results, we have put forward a theory that should explain the observations made, and it has been shown in subsequent pages how far the theory agrees to the observations.

This work was commenced in 1924-25 when the first eight crosses were made—these crosses have now been carried to the F_6 generation.

Description of Parents.

Types	Habit	Foliage colour	Flowers	Petals	Filaments	Anthers	Styles	Stigma	Seed
1	Most of the branching at the base, open.	Light bluish green.	Very large, open	Broad, white with pink tinge and violet markings.	Upper half blue	White	Blue	White with pink tinge.	Pure yellow, bold.
8	Branching above and below, open, crowded.	Light green	Medium sized, open.	Narrow, medium, deep blue.	Blue	Blue	Blue	White	Fawn, bold.
11	A good deal of branching from base, open, spreading.	Light bluish green.	Medium, not very open.	Very narrow, deep lilac.	White, very little blue below anther on one side.	Blue	Deep blue throughout.	Deep purple	Deep fawn, bold.
12	Much branched, very erect, crowded and compact.	Dark green	Small, not well open.	Very narrow, white with blue tinge.	White	White	White	White	Brown, small.
22	Much branching below and above, somewhat spreading.	Light green	Medium, mediumly open.	Broad, pale blue.	White	Blue	White	White	Brown, bold.
121	Branching both above and below erect, crowded, compact.	Dark green	Large, open	Broad, lilac	Purplish blue	Very pale blue.	Pale blue	White	Brown, small.
124	....	..	Small	White	White	White	White	White	Yellow, small.

Description of the F_1.

Crosses	Habit	Foliage colour	Flowers	Petals	Filaments	Anthers	Styles	Stigma
12 × 1 1 × 12	....	Green . .	Large, open .	Broad, blue . .	Like T_1 . .	Blue .	Blue .	White.
12 × 8 8 × 12	Less branching above than Type 8.	Green . .	Large, open .	Broader, and lighter blue than Type 8.	Lighter blue than Type 8.	Blue .	Lighter blue than Type 8.	White.
12 × 11 11 × 12	More spreading and open than Type 12.	Dark green .	Large, open .	Broader than either parent, blue.	Blue like Type 11 .	Blue .	Blue .	White.
12 × 22 22 × 12	Like Type 22 . .	Dark green .	Medium and mediumly open.	Broad, blue . .	Upper half pale blue, deeper on the inner side.	Blue .	Blue .	White.
121 × 1 1 × 121		..	Large, open .	Broad, blue . .	Blue like Type 121	Blue .	Blue like Type 121.	White.
121 × 8 8 × 121		Like Type 11 .	Like Type 121 .	Broad like Type 121, blue, lighter than Type 8.	Deep blue like Type 8.	Blue like Type 8.	Blue .	White.
121 × 11 11 × 121	Like Type 11 . .	Like Type 11 .	Large, open .	Lilac like Type 121	Like Type 11 .	Blue .	Blue .	White.
121 × 22 22 × 121	Like Type 22 . .	Intermediate between Type 22 and Type 121.	Large, open .	Broad, blue . .	Blue . . .	Blue .	Very faint blue.	White.
12 × 121 121 × 12				Blue . . .	Blue . . .	Blue .	Blue .	White.
1 × 11 11 × 1				Blue . . .	Blue like Type 11 .	Blue .	Blue .	Purple.
1 × 22 22 × 1				Blue . . .	Blue . . .	Blue .	Blue .	White.
1 × 124				Blue . . .	Blue . . .	Blue .	Blue .	Purple.

II. Description of the Results of the Crosses.

Cross No. 1. Type 12 with Type 1.

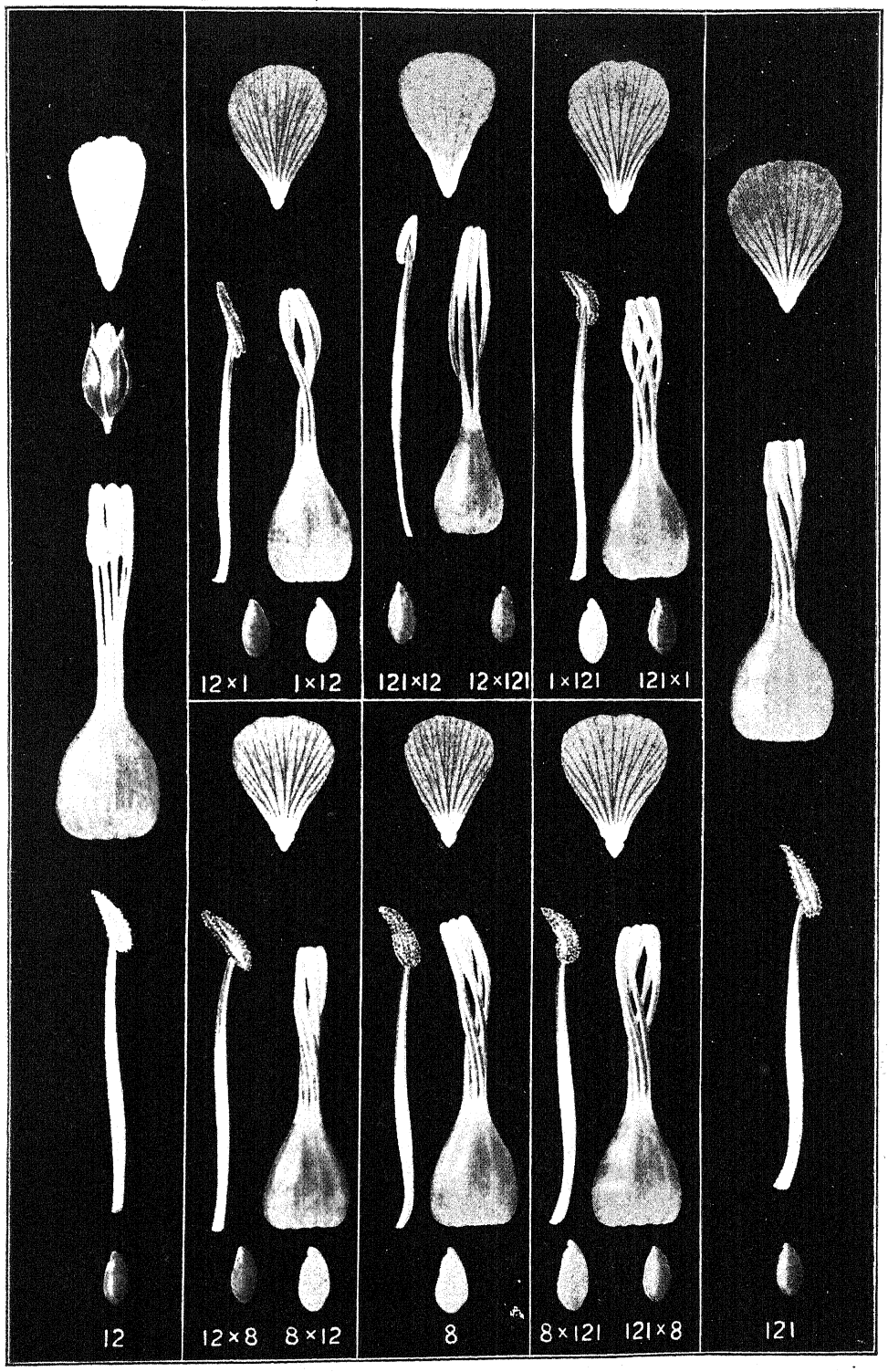
Petals. Type 12 has white petals (Plate I) with a very faint bluish tinge; the petals are narrow and have a crimped appearance. Type 1 has white, broad, non-crimped petals with a faint pink tinge; the petals of Type 1 also have lilac veins (Plate II).

The F_1 had bright blue petals (Plate I) and the F_2 population showed the following phenotypes of petal colour and their frequencies :—

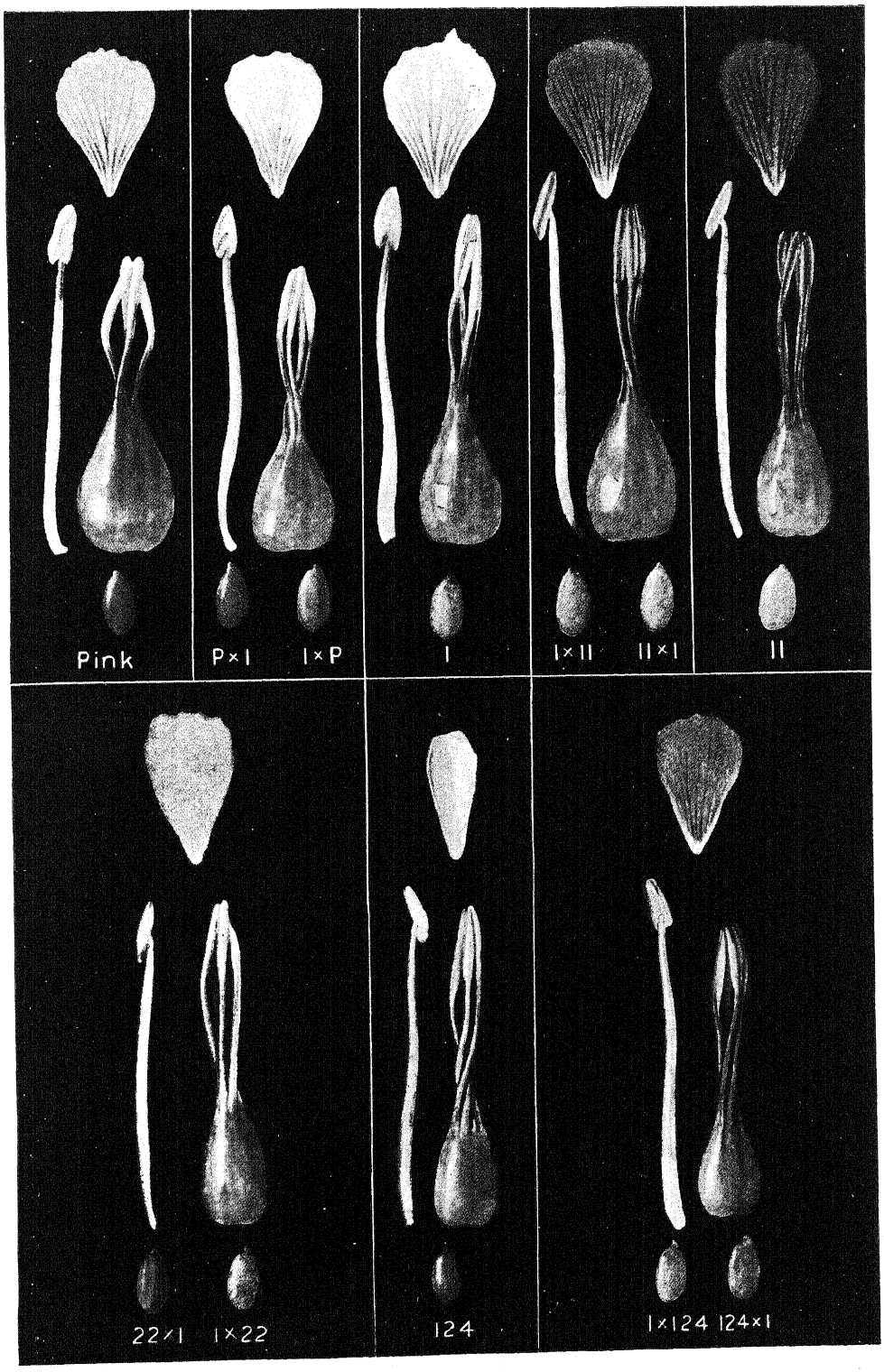
	Blue like F_1	White like Type 12	White like Type 1	White non-crimped	
12×1.	115	32	29	3	=179
1×12	92	26	38	7	=163
Total observed	207	58	67	10	=342
„ expected	192·6	64·2	64·2	21·4	=342·4
Ratio observed	9·68	: 2·71	: 3·13	: 0·47	
„ expected	9	: 3	: 3	: 1	

X^2=7·78. The fit is not good owing to the deficiency in the double recessive class. The non-crimped phenotype is the double recessive; it differs from both the parents. It is different from Type 12 in possessing broader petals which lack the bluish tinge and crimped appearance, while it differs from Type 1 in not possessing even the slight pink tinge and lilac veins. The petal colour of the double recessive is full white, and it has been called " non-crimped " white. In 51 cultures in F_3 the following segregations occurred :—

Number of cultures and nature of parent plants in F_2	Segregations	Frequencies	
		Observed	Expected
27 cultures from plants with blue petals, like F_1, in F_2.	Pure	2	3
	Like F_2 . . .	12	12
	3 blue : 1 Type 1 .	10	6
	3 blue : 1 Type 12 .	3	6



INHERITANCE OF CHARACTERS IN INDIAN LINSEED.



INHERITANCE OF CHARACTERS IN INDIAN LINSEED.

Number of cultures and nature of parent plants in F_2	Segregations	Frequencies	
		Observed	Expected
8 cultures from plants like Type 1 in F_2 .	Pure	3	2·6
	3 Type 1 : 1 non-crimped	5	5·4
9 cultures from plants like Type 12 in F_2 .	Pure	3	3
	3 Type 12 : 1 non-crimped . . .	6	6
7 cultures from plants which were "non-crimped" in F_2.	Pure	7	7

The behaviour of F_3, therefore, confirms the theory that the cross shows a dihybrid segregation in petal colour.

Filaments, styles and anthers. The F_1 has blue filaments and a blue style, and in F_2 all phenotypes with blue petals or with petals like Type 1 have blue filaments and style. The frequencies of these characters, therefore, coincide with the frequencies for the petal phenotypes. The anthers are blue in F_1 and blue in F_2 in the phenotype with blue petals.

Stigma. The F_1 has a white stigma, and in F_2 white stigmas are dominant to purple stigmas on a 3 : 1 ratio, in the phenotype with blue petals; all the other petal phenotypes in F_2 have white stigmas. In this, the first cross which was observed, the diagnosis of stigma colour in F_2 was not satisfactory for the reasons explained on page 3, and the above results are based on the F_3 observations. In F_3 in the 27 cultures with blue petals we found :—

Number of cultures and nature of parent plants in F_2	Segregations	Observed	Expected
19 cultures from plants with white stigma in F_2.	Pure	6	6·33
	Segregating . .	13	12·66
8 cultures from plants with purple stigma in F_2.	Pure	8	8·34

In the cultures segregating for stigma colour in F_3, we found a total of—

	White stigma	Purple stigma	
Observed	166	58	=224
Expected	168	56	=224

Seed. Type 1 has a bold yellow seed and Type 12 a small brown seed, and the F_1 has brown seed.

The following were the observed phenotypes for seed colour, and their frequencies, together with their distribution in the four petal phenotypes, in the F_2 population, cross and reciprocal :—

Petal colour	Seed colour	Frequencies	
		Observed	Expected
Blue like F_1	Brown	149	148·5
Blue like F_1	Fawn	49	49·5
Like Type 12	Brown	39	38·25
Like Type 12	Fawn	12	12·75
Like Type 1	Grey	47	44·25
Like Type 1	Yellow	12	14·75
"Non-crimped"	Grey	5	6
"Non-crimped"	Yellow	3	2

The total frequencies of the four seed phenotypes are :—

	Brown	Fawn	Grey	Yellow	
Observed	188	61	52	15	=316
Expected	177·75	59·25	59·25	19·75	=316
X^2=2·669	..	..	..	..	..

Grey seeds are liable to be wrongly diagnosed as brown and the slight discrepancy between observation and theory in these phenotypes is probably due to difficulty in diagnosis.

Cross No. 2. Type 12 with Type 8.

Petals. Type 8 has bright blue petals and the F_1 resembles Type 8 (Plate I) but the petals are a slightly lighter blue.

The F_2 population showed the following phenotypes and frequencies for petal colour :—

	Blue like Type 8	White like Type 12	
12×8	162	57	=219
8×12	139	50	=189
Total observed	301	107	=408
„ expected	306	102	=408
Ratio „	3	: 1	
„ observed	2·95	: 1·05	

$$\frac{\text{Deviation}}{\text{Probable error}} = \frac{5}{5{\cdot}85} = 0{\cdot}86.$$ The fit is very good.

In F_3 the following segregations were observed :—

Number of cultures and nature of parent plants	Segregations	Frequencies	
		Observed	Expected
15 cultures from plants with blue petals like F_1 in F_2	Pure	4	5
	Like F_2 . . .	11	10
6 cultures from plants like Type 12 in F_2 .	Pure	6	6

The behaviour of F_3 confirms the theory of a single factor difference between the parents. The F_1 was back-crossed with Type 12 and the resulting population consisted of nearly equal numbers of individuals with blue and white petals :—

	Blue	White	
Observed	38	32	=70
Expected	35	35	=70

$$\frac{\text{Deviation}}{\text{Probable error}} = \frac{3}{2{\cdot}82} = 1{\cdot}06.$$

Filaments, styles and anthers. The F_1 had blue filaments, anthers and style, and in F_2 we observed that all plants with blue petals had blue filaments, anthers and styles.

Stigma. The F_1 had a white stigma and in F_2, in the phenotype with blue petals, we obtained :—

—	Purple stigma		White stigma	
Frequency observed . . .	60		241	=301
„ expected . . .	56·4		244·6	=301
Ratio observed	3·13	:	12·82	
„ expected	3	:	13	

The F_3 observations agree with the 3 : 13 ratio of purple to white stigmas in F_2.

Seed. Type 8 has a bold fawn seed and Type 12 has a small brown seed. The F_1 had brown seed and in F_2 we observed :—

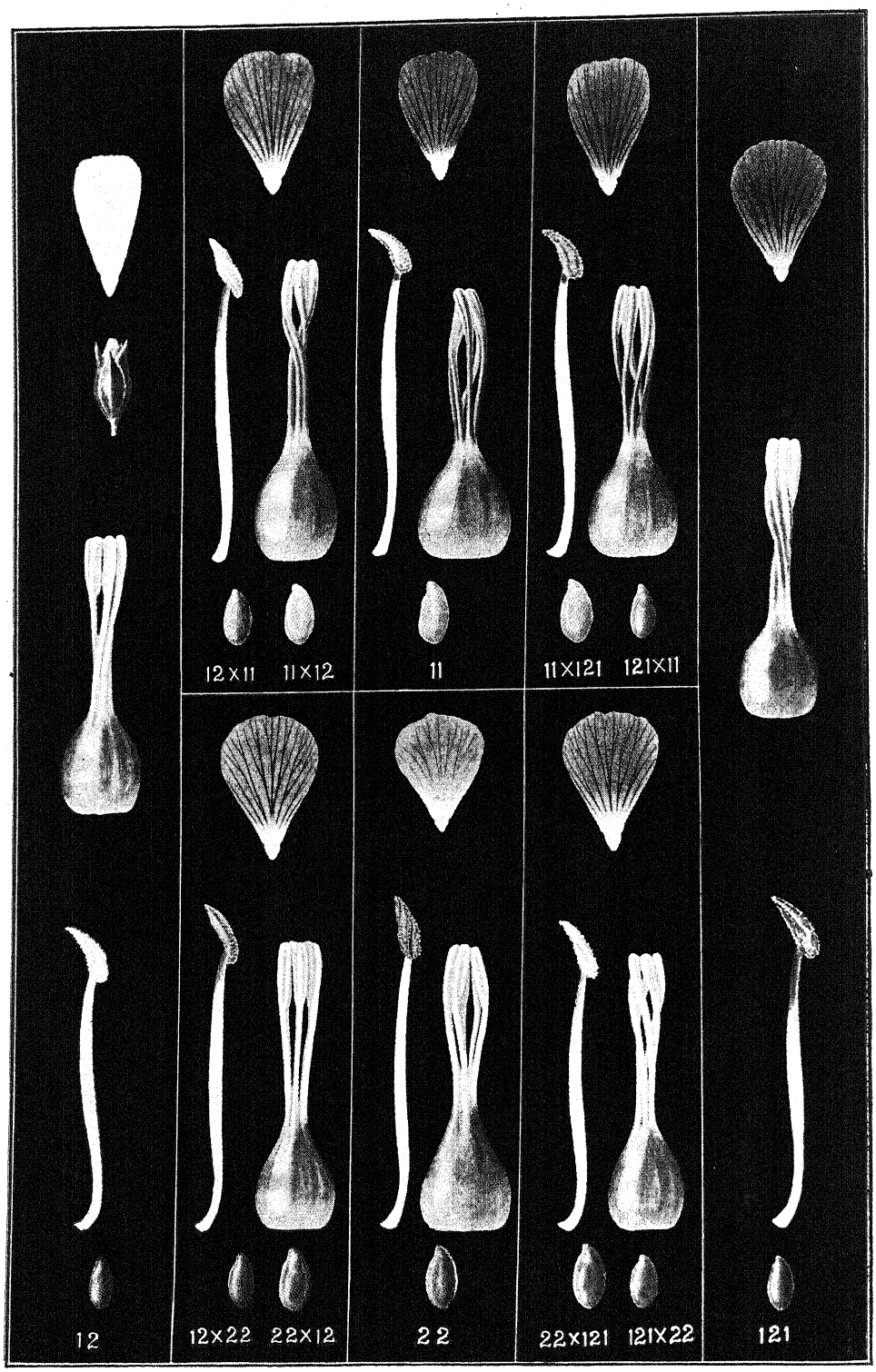
Petal colour	Seed colour	Frequencies	
		Observed	Expected
Blue like Type 8	Brown . . .	196	210
„ like Type 8	Fawn . . .	84	70
White like Type 12	Brown . . .	75	73·5
„ like Type 12	Fawn	23	24·5

The total frequencies of browns and fawns are therefore :—

—	Brown		Fawn	
Observed	271		107	=378
Expected	283·5		94·5	=378
Ratio observed	2·87	:	1·13	
„ expected	3		1	

$$\frac{\text{Deviation}}{\text{Probable error}} = \frac{12{\cdot}5}{5{\cdot}66} = 2{\cdot}2.$$

The fit is fairly close.



INHERITANCE OF CHARACTERS IN INDIAN LINSEED.

CROSS No. 3. TYPE 12 WITH TYPE 11.

Petals. Type 11 has a deep lilac petal and the F_1 has a bright blue petal (Plate III); the F_2 population showed the following phenotypes and frequencies :—

	Blue like F_1	Lilac like Type 11	White like Type 12	
12×11	115	35	49	=199
11×12	117	26	56	=199
Total observed . . .	232	61	105	=398
„ expected . . .	223·92	74·64	99·52	=398·08
Ratio observed . .	9·73 :	2·56 :	4·4	
„ expected . . .	9 :	3 :	4	

x^2=3·06. There is a slight deficiency in the purple class and the fit is not good. The F_2 population was grown again in the following year and the frequencies obtained were :—

	Blue	Lilac	White	
Observed	284	87	126	=497
Expected	279·54	93·18	124·24	=496·96
Ratio observed . . .	9·14 :	2·8 :	4·06	
„ expected . . .	9 :	3 :	4	

x^2=0·626. The fit is satisfactory in this case.

In F_3 the following segregations were observed :—

Number of cultures and nature of parent plants	Segregations	Frequencies	
		Observed	Expected
19 cultures from plants with blue petals like F_1 in F_2.	Pure	1	2·1
	Like F_2 . . .	10	8·4
	3 Blue : 1 Type 12 .	5	4·2
	3 Blue : 1 Type 11 .	3	4·2
10 cultures from plants like Type 11 in F_2 .	Pure	3	3·3
	3 Lilac : 1 Type 12 .	7	6·6
7 cultures from plants white like Type 12 in F_2.	Pure	7	7

The evidence of F_3 supports the 9 : 3 : 4 ratio observed in F_2.

Filaments, styles and anthers. The inheritance of blue colour in anthers, filaments and style is the same in this cross as in Cross No. 2 between Types 12 and 8; all phenotypes with coloured, blue or lilac, petals have colour in anthers, filaments and style. The blue colour in the filaments of Type 11 is, however, different to that in any other type as the colour is here restricted to the extreme top of the filament, and therefore this filament is liable to be confused with white. In F_2 we observed the following distribution of coloured filaments :—

Petal colour	Filament colour		
	Blue	Blue like Type 11	
Blue . . .	Observed 66 . .	166	=232
	Expected 58 . .	174	=232
Lilac . . .	Observed 18 . .	43	=61
	Expected 15·25 . .	45·75	=61
Totals . .	Observed 84 . .	209	=293
	Expected 73·25 . .	219·75	=293

Ratio observed 2·85 : 1·15.
„ expected 3·0 : 1.

The type 11 filament is, therefore, dominant to the normal blue filament on a 3 : 1 ratio.

In F_3 generation, in 29 cultures with coloured petals, the following segregation in filament colour was observed :—

Number of cultures and nature of parent plants in F_2	Segregations	Frequencies	
		Observed	Expected
8 cultures from plants with blue filaments .	Pure	8	8
21 cultures from plants with filaments like Type 11.	Pure like type 11 . .	6	7
	1 Blue : 3 Type 11 .	15	14

The frequencies 8 : 15 : 6 are in close approximation to the expected 1 : 2 : 1 ratio.

Stigma. Type 11 has a very distinct purple stigma and Type 12 a white stigma. The F_1 in this cross had a white stigma in which a faint blue tinge was sometimes visible. In F_2, purple stigmas are only found in plants with coloured, blue or lilac, petals and in the second F_2 population we observed :—

	Purple stigma	White stigma	
In blue petals	89	195	=284
In lilac ,, ...	27	60	=87
Total observed	116	255	=371
,, expected	92·75	278·25	=371
Ratio observed	1·25	: 2·75	
,, expected	1	: 3	

In F_3 there were 29 cultures from plants with coloured petals in F_2, and their behaviour as regards stigma colour was as follows :—

Number of cultures and nature of plants	Segregations	Frequencies	
		Observed	Expected
10 cultures from plants with purple stigma .	Pure	10	10
19 cultures from plants with white stigma .	Pure	3	6·3
	Segregating . . .	16	12·6

The fit is not very good but the diagnosis is difficult.

Seed. Type 11 has a bold fawn seed, of a darker tint than that of Type 8, and the F_1 had brown seed, and in F_2 we observed :—

Petal colour	Seed colour	Frequencies	
		Observed	Expected
Blue like F_1	Brown . . .	176	168
	Fawn	48	56
Lilac like Type 11	Brown . . .	42	45·75
	Fawn	19	15·25
White	Brown . . .	69	78
	Fawn	35	26

	Total Brown	Total Fawn	
Observed	287	102	=389
Expected	291·75	97·25	=389

$$\frac{\text{Deviation}}{\text{Probable error}} = \frac{4{\cdot}75}{5{\cdot}75} = 0{\cdot}826.$$

Ratio observed	2·95	:	1·05
„ expected	3	:	1

Cross No. 4. Type 12 with Type 22.

Petals. Type 22 has a pale blue petal and the F_1 is a deeper blue like Type 8 (Plate III). The F_2 population showed the following phenotypes and frequencies :—

	Blue like F_1	Blue like Type 22	White like Type 12	White	
12×22 . .	106	37	32	11	=186
22×12 . .	99	43	44	15	=201
Total observed .	205	80	76	26	=387
„ expected .	217·8	72·6	72·6	24·2	=387·2
Ratio observed .	9·48 :	3·3 :	3·14 :	1·07	
„ expected .	9 :	3 :	3 :	1	

x^2=1·69. The fit is good.

The F_2 population was grown again in the next season and gave the following frequencies :—

	Blue	Type 22	Type 12	White	
Observed . .	98	31	36	13	=178
Expected . .	100·125	33·375	33·375	11·125	=178
Ratio observed .	8·8 :	2·78 :	3·24 :	1·17	
„ expected .	9 :	3 :	3 :	1	

x^2=0·736. The fit is good.

In F_3 the following segregations were noted :—

Number of cultures and nature of parent plants	Segregations	Frequencies	
		Observed	Expected
15 cultures from plants with blue petals like F_1.	Pure	1	1·67
	Like F_2 . . .	7	6·67
	3 Blue : 1 Type 12 .	4	3·33
	3 Blue : 1 Type 22 .	3	3·33
8 cultures from plants like Type 22 in F_2 .	Pure	4	2·6
	3 Type 22 : 1 white .	4	5·4
6 cultures from plants like Type 12 in F_2 .	Pure	2	2
	3 Type 12 : 1 white .	4	4
3 cultures from white plants in F_2 . .	Pure	3	3

The results of F_3 confirm the 9 : 3 : 3 : 1 segregation observed in F_2.

Anthers. Type 22 has blue anthers, and in F_2 and in F_3 all plants with blue petals or petals like Type 22 have blue anthers ; the inheritance of colour in the anther in the whole cross is, therefore, on a 3 : 1 ratio.

Filaments. Both parents have white filaments but the F_1 has blue filaments, and in F_2 in the phenotype with petals " blue like F_1 " we observed :—

	Blue filaments		White filaments	
Observed	155		50	=205
Expected	153·75		51·25	=205
Ratio observed	3·02	:	0·98	
„ expected	3	:	1	

In phenotypes, with petals " like Type 22", " like Type 12 " and white, all filaments are white. In the whole cross, therefore, we have in F_2 :—

	Blue filaments	White filaments	
Observed	155	232	=387
Expected on 27 : 37 . . .	163	224	=387

Style. In the phenotype with petals blue " like F_1 " all plants have blue styles, all other phenotypes of petal colour have white styles. Colour in the style in the whole cross is, therefore, inherited on a 9 : 7 ratio.

Stigma. Both parents have white stigmas and the F_1 and all plants in F_2 and F_3 have white stigmas.

Seed. Both parents have brown seed, that of Type 22 however is bold while that of Type 12 is small ; the F_1 had brown seed and all individuals in F_2 and F_3 had brown seeds.

Cross No. 5. Type 121 with Type 1.

Petals. In crosses 5, 6, 7 and 8 the same four parents (Types 1, 8, 11 and 22) were crossed with Type 121. Type 121 has a lilac petal and in the cross with Type 1 the F_1 has a blue petal (Plate I) and the F_2 population showed the following phenotypes and frequencies :—

	Blue like F_1	Lilac like Type 121	White like Type 1	Pink	
121×1 . . .	84	33	38	10	=165
1×121 . . .	85	28	24	12	=149
Total observed . .	169	61	62	22	=314
„ expected . .	176·85	58·95	58·95	19·65	=314·44
Ratio observed . .	8·61 :	3·12 :	3·15 :	1·12	
„ expected . .	9 :	3 :	3 :	1	

χ^2=0·83. The fit is good.

The double recessive is a new phenotype with pink petals (Plate II)—pink being the basic colour of petals in linseed. Among the 123 types originally isolated at Pusa none had pink petals.

In F_3 the following segregations were observed :—

Number of cultures and nature of parent plants in F_2	Segregations	Frequencies	
		Observed	Expected
19 cultures from plants with blue petals like F_1 in F_2.	Pure	4	2·1
	Like F_2 . . .	9	8·4
	3 Blue : 1 purple Type 121.	4	4·2
	3 Blue : 1 Type 1 .	2	4·2

Number of cultures and nature of parent plants in F_2	Segregations	Frequencies	
		Observed	Expected
8 cultures from plants with purple petals like Type 121.	Pure	1	2·6
	3 Purple : 1 Pink . .	7	5·4
8 cultures from plants with white petals like Type 1.	Pure	3	2·6
	3 Type 1 : 1 pink .	5	5·4
6 cultures from plants with pink petals .	Pure	6	6

The behaviour of F_3 confirms the theory of a dihybrid segregation in F_2.

The double recessive, pink, phenotype was crossed with the white, Type 1, parent. The F_1 (Plate II) was like Type 1, and in the second hybrid generation the following frequencies were observed :—

	Type 1	Pink	
Observed	210	72	=282
Expected	211·5	70·5	=282

$$\frac{\text{Deviation}}{\text{Probable error}} = \frac{1{\cdot}5}{4{\cdot}9} = 0{\cdot}306.$$

This clearly indicates a monohybrid difference between pink and Type 1 in petal colour.

Anthers, filaments and styles. Type 1 has white anthers and Type 121 has blue anthers. The F_1 had blue anthers, and blue anthers are present in F_2 in phenotypes with blue or lilac petals. Blue filaments and styles occur in both parents and in F_1 and are present in all individuals in F_2.

Stigma. The F_1 had a white stigma and in F_2 we obtain in phenotypes with blue and lilac petals :—

	White stigmas	Purple stigmas	
Observed	174	56	=230
Expected	172·5	57·5	=230
Ratio observed	2·98	: 1·02	
„ expected	3	: 1	

In F_3 we observed :—

Number of cultures and nature of parent plants in F_2	Segregations	Frequencies	
		Observed	Expected
12 cultures from plants with purple stigmas	Pure	12	12
15 cultures from plants with white stigmas	3 white : 1 purple .	8	10
	Pure white . . .	7	5

Seed. Type 121 has small brown seed and Type 1 has bold yellow seed. The F_1 had a brown seed and the segregation was the same as in the cross between Type 12 and Type 1, brown and fawn seeds occur in phenotypes with blue or lilac petals and grey and yellow seed is found with Type 1 and pink phenotypes.

In F_2 we observed :—

Petal colour	Seed colour	Frequencies	
		Observed	Expected
Blue like F_1	Brown . . .	130	123·75
	Fawn	35	41·25
Lilac like Type 121	Brown . . .	46	45
	Fawn	14	15
White like Type 1	Grey	48	45·75
	Yellow . . .	13	15·25
Pink	Grey	15	15·75
	Yellow . . .	6	5·25

	Brown	Fawn	Grey	Yellow	
Total observed . .	176	50	63	19	=308
„ expected . .	173·25	57·75	57·75	19·25	=308
Ratio observed . .	9·14 :	2·6 :	3·27 :	0·99	
„ expected . .	9 :	3 :	3 :	1	

In a cross between the pink double recessive and Type 1 the pink parent had grey seed and the results of this cross were :—

	Grey	Yellow	
Observed	263	89	=352
Expected	264	88	=352

$$\frac{\text{Deviation}}{\text{Probable error}} = \frac{1}{5{\cdot}47} = 0{\cdot}18.$$

A satisfactory agreement between observation and theory.

Cross No. 6. Type 121 with Type 8.

Petals. The parents have already been described and the F_1 had a blue petal (Plate I) ; in F_2 the following phenotypes and frequencies were observed :—

	Blue like F_1	Lilac like Type 121	
121×8	127	44	=171
8×121	134	43	=177
Total observed	261	87	=348
„ expected	261	87	=348
Ratio observed	3	: 1	
„ expected	3	: 1	

The fit is perfect.

In F_3 the following segregations were observed :—

Number of cultures and nature of parent plants in F_2	Segregations	Formulæ of parents	Frequencies	
			Observed	Expected
13 cultures from plants with blue petals like F_1 in F_2.	Pure . .	F F . .	5	4·3
	Like F_2 .	F f . .	8	8·6
8 cultures from plants with purple petal like Type 121.	Pure . .	f f . .	8	8

Filaments, styles and anthers. Blue anthers, filaments and styles occur in all individuals in this cross.

Stigma. In stigma colour this cross resembles that between Types 12 and 8. The F_1 has a white stigma and a 3 : 13 ratio was obtained in F_2 as follows :—

	White stigmas	Purple stigmas	
Observed	299	49	=348
Expected on 13 : 3	282·75	65·25	=348
Ratio observed	13·75	: 2·25	
„ expected	13	: 3	

In this cross, however, purple stigmas occur in both phenotypes for petal colour. In F_3 we observe :—

Number of cultures and nature of parent plants in F_2	Segregations	Formulæ	Frequencies	
			Observed	Expected
4 cultures from plants with purple stigmas.	Pure . .	1 P P i i	3	1·3
	3 purple : 1 white	2 P p i i	1	2·7
15 cultures from plants with white stigmas.	Pure . .	1 PPII, 1 ppII, 2 PpII, 2 ppIi, 1 ppii	8	8·08
	3 white : 1 purple	2 P P I i	*7	6·92
	13 white : 3 purple	4 P p I i		

The F_3 results confirm the F_2 theory.

Seed. The behaviour of this cross as regards the inheritance of seed colour is exactly the same as that of the cross between Type 12 and Type 8. In F_2 we observed :—

Flower colour	Seed colour	Frequencies	
		Observed	Expected
Blue	Brown . . .	186	190·5
	Fawn	68	63·5
Lilac	Brown . . .	53	63·75
	Fawn	32	21·25

* The distinction of these 2 segregates was not possible in the small number of plants raised in the cultures in F_3.

	Brown	Fawn	
Total observed	239	100	=339
,, expected	254·25	84·75	=339
Ratio observed	2·82	: 1·18	
,, expected	3	: 1	

$$\frac{\text{Deviation}}{\text{Probable error}} = \frac{15{\cdot}25}{5{\cdot}37} = 2{\cdot}84.$$

Cross No. 7. Type 121 with Type 11.

Petals. Both the parents have lilac petals but that of Type 11 has a deeper colour than that of Type 121 (Plate III). The F_1 had a lilac petal like that of Type 121, and in F_2 the following segregation was observed :—

	Lilac like Type 121	Lilac deep like Type 11	
121×11	139	46	=185
11×121	145	44	=189
Total observed	284	90	=374
,, expected	280·5	93·5	=374
Ratio observed	3·04	: 0·96	
,, expected	3	: 1	

$$\frac{\text{Deviation}}{\text{Probable error}} = \frac{3{\cdot}5}{5{\cdot}6} = 0{\cdot}62.$$ The fit is very good.

Number of cultures and nature of parent plants in F_2	Segregations	Frequencies	
		Observed	Expected
7 cultures from plants with lilac petals like Type 121 in F_2.	Pure	2	2·3
	3 Type 121 : 1 Type 11 .	5	4·6
2 cultures from plants with lilac petal like Type 11.	Pure	2	2

The F_3 population confirms the theory of a monohybrid difference between the two parents. A repetition of the F_2 in the following season gave :—

	Lilac like Type 121	Lilac like Type 11	
Observed	110	41	=151
Expected	113·25	37·75	=151

$$\frac{\text{Deviation}}{\text{Probable error}} = \frac{3{\cdot}25}{3{\cdot}59} = 0{\cdot}90,$$

Filaments, styles and anthers. Both parents possess blue anthers, filaments and styles and these characters are present in F_1 and in all the plants in F_2. The blue colour of the filament in Type 11 is, however, restricted to the distal end just below the anther as in the case of Cross No. 3. The F_1 filament resembles that of Type 11, and in the second F_2 population we obtained the following frequencies :—

	Blue like Type 121	Intermediate resembling Type 11	Blue like Type 11	
	30	67	53	
Observed	30	120		=150
Expected	37·5	112·5		=150
Ratio observed	1·25	: 2·75		
„ expected	1	: 3		

The diagnosis of this character is difficult in this cross and we could obtain no definite result in the first F_2 population. It was only when increased experience in diagnosis had rendered the identification of phenotypes more certain that we were able to arrive at a definite result in a repetition of the F_2 generation.

Stigma. Type 11 has a deep purple stigma, while that of Type 121 is white. The F_1 had a white stigma and in the F_2 populations the following frequencies were observed :—

Petal phenotype	Lilac petal like Type 121 and white stigma	Lilac petal like Type 121 and purple stigma	Lilac petal like Type 11 and white stigma	Lilac petal like Type 11 and purple stigma	
Observed	259	25	23	67	=374
Expected on 9 : 3 : 3 : 1 . .	210·33	70·11	70·11	23·37	=373·92
Observed in repetition . .	98	12	10	31	=151
Expected on 9 : 3 : 3 : 1 . .	84·96	28·32	28·32	9·44	=151·04

These frequencies clearly indicate linkage between the deep lilac colour of the petal in Type 11 and the purple colour in the stigma in this type, the frequency of the

parental types being considerably above expectation, while each character taken singly shows a good 3 : 1 fit.

	White stigma	Purple stigma	Total	Deviation divided by Probable error
Observed	282	92	374	0·26
Expected	280·5	93·5	374	..
Observed	108	43	151	1·45
Expected	113·25	37·75	151	..

Ratio observed 3·02 : 0·98

„ expected 2·86 : 1·14

In F_3 the behaviour of the selections made in F_2 was as follows :—

	Segregation	Formulæ	Frequencies	
			Observed	Expected
2 cultures with purple stigma	Pure . . .	P P i i .	2	2
6 cultures with white stigma .	Pure . . .	1 P P I I .	1	2
	3 white : 1 purple .	2 P P I i .	5	4

This agrees with the 3 : 1 ratio obtained in F_2.

The intensity of linkage between the factors for light petal colour and white stigma can be ascertained by calculating the cross-over value. Applying the Product Ratio method which has been recommended for general use by one of us [Alam, 1929], we get a cross-over value of 13·95 per cent.

Seed. The seed colour factors involved in this cross are the same as in the cross of Type 12 with Type 11, and we should expect a ratio of 3 brown : 1 fawn in each phenotype of petal colour.

In the first F_2 population we actually observed :—

Petal colour	Seed colour	Frequencies	
		Observed	Expected
Lilac like Type 121	Brown . .	249	202·5
	Fawn . .	21	67·5
Deep lilac like Type 11	Brown . .	26	61·5
	Fawn . .	56	20·5

In this cross our observations dealt with a contrast of brown with fawn colour in the seed with the result that the minor colour distinction between dark fawn and light fawn, due to the segregation of X, was not recorded, as in the case of Cross No. 3 between Types 12 and 11.

	Brown	Fawn	
Total observed	275	77	=352
„ expected	264	88	=352

$$\frac{\text{Deviation}}{\text{Probable error}} = \frac{11}{5{\cdot}47} = 2{\cdot}01.$$

The total of brown to fawn in the whole cross gives a good 3 : 1 fit but in each petal phenotype this ratio is not realised. If we set out the observed frequencies for seed and petal colour, it is apparent that brown seed colour is linked with the Type 121 petal.

	Petal Type 121 brown seed	Petal Type 121 fawn seed	Petal Type 11 brown seed	Petal Type 11 fawn seed	
Observed	249	21	26	56	=352
Expected on 9 : 3 : 3 : 1 .	198	66	66	22	=352

The frequency of the parental types is much above expectation and we infer linkage between deep lilac in the petal and fawn colour in the seed. The linkage intensity, in this case as well, has been ascertained by calculating the cross-over value and comes to 15 per cent. when calculated by the Product Ratio method.

If we consider the inheritance of stigma colour and seed colour together, we obtain the following :—

	White stigma brown seed	Purple stigma brown seed	White stigma fawn seed	Purple stigma fawn seed	Total
Observed	259	14	16	63	352
Expected on 9 : 3 : 3 : 1 .	198	66	66	22	352

Here again the frequencies of the parental combinations are considerably above expectation, and there is evident linkage between the white stigma and brown seed. Calculation by the same Product Ratio method shows a cross-over value of 9·3 per cent.

Summary of observations on Linkage in Cross No. 7.

	White stigma Petal Type 121	White stigma Petal Type 11	Purple stigma Petal Type 121	Purple stigma Petal Type 11	
Observed	259	23	25	67	=374
Calculated on 9 : 3 : 3 : 1 .	210·33	70·11	70·11	23·37	=373·92

	Petal Type 121 Brown seed	Petal Type 121 Fawn seed	Petal Type 11 Brown seed	Petal Type 11 Fawn seed	
Observed	249	21	26	56	=352
Calculated on 9 : 3 : 3 : 1 .	198	66	66	22	=352

	White stigma Brown seed	White stigma Fawn seed	Purple stigma Brown seed	Purple stigma Fawn seed	
Observed	259	16	14	63	=352
Calculated on 9 : 3 : 3 : 1 .	198	66	66	22	=352

Cross No. 8. Type 121 with type 22.

Petals. The parents have already been described and the F_1 had bright blue petals (Plate III).

In F_2 the following phenotypes of petal colour and frequencies were observed :—

	Blue like F_1	Lilac like Type 121	Pale blue like Type 22	Pale lilac	
121×22 . . .	109	29	59		=197
22×121 . . .	102	34	62		=198
Total observed . .	211	63	121		=395
„ expected . .	223	74·1	98·8		
Ratio observed . .	8·55 :	2·55 :	4·9		
„ expected . .	9 :	3 :	4		

X^2=7·226. The fit is not good, the third class being in considerable excess. This distribution of phenotypes can only be explained on the assumption that more than two factors are involved in this cross. This question has been discussed after giving the theory on page 45.

A repetition of the F_2 population gave :—

	Blue like F_1	Lilac like Type 121	Pale blue like Type 22	Pale lilac	
Observed . . .	95	29	51		=175
Expected . . .	98·46	32·82	43·76		=175·04
Ratio observed . .	8·72 :	2·66 :	4·72		
„ expected . .	9 :	3 :	4		

x^2=1·765.

In F_3 the following segregations were observed :—

Number of cultures and nature of parent plants in F_2	Segregations	Frequencies	
		Observed	Expected on dihybrid basis
7 cultures from plants with blue petals like F_1 in F_2.	Pure	0	0·78
	Like F_2	4	3·10
	3 blue : 1 Type 22 . .	2	1·56
	3 blue : 1 Type 121 . .	1	1·56
4 cultures from plants with lilac petals like Type 121.	Pure	2	1·3
	3 lilac Type 121 : 1 Type 22 or pale lilac . . .	2	2·6
7 cultures from plants like Type 22 or pale lilac.	Pure	7	7

The results of F_3 agree with those of F_2 and the fit is not good even in F_3 ; at a later place (page 45) reasons are given which show that the segregation is not on a dihybird basis.

Filaments and anthers. Anthers are blue in both parents and in F_1 and in all plants in F_2. The filaments are blue in Type 121 and in the F_1 but white in Type 22. In F_2 blue filaments and white filaments occur in the phenotypes with petals blue "like F_1" or lilac "like Type 121," in the following frequencies :—

	Blue filaments	White filaments	
Observed	260	14	=274
Expected on 15 : 1	256·9	17·1	=274
Ratio observed	15·2 :	0·8	
„ expected	15 :	1	

In F_3 in the 11 cultures with blue or lilac petals two were from plants with white filaments and bred true to this character in F_3. In the remaining nine cultures from plants with blue filaments, five were pure for blue and four split into blue and white, the latter colour being recessive. All the cultures were badly damaged by disease, and it is extremely probable that some of the cultures which appeared as pure blue filaments were really splitting on a 15 : 1 ratio.

Style. In style colour we observe that F_1 has a blue style and in F_2 all blue and lilac flowers have blue styles.

Stigma. The stigma is white in both parents and in F_1 and in all plants in F_2.

Seed. Both parents have brown seed and as in the cross of Type 12 and Type 22 there is no segregation of seed colour to be observed in F_2.

Cross No. 9. Type 12 with Type 121.

Petals. This cross is between the two types each of which has been crossed with Types 1, 8, 11 and 22 in the first eight crosses. The F_1 had a bright blue petal (Plate I), and in F_2 the following phenotypic frequencies were obtained :—

	Blue like F_1	Lilac like Type 121	White like Type 12	White	
121×12	136	37	66		=239
12×121	114	54	47		=215
Total observed	250	91	113		=454
„ expected	255·6	85·2	114·6		=455·4
Ratio observed	8·74 :	3·17 :	4·54		
„ expected	9 :	3 :	4		

X^2=0·532. The fit is good. This cross resembles the cross of Type 12 with Type 11.

In F_3 the following segregations were observed :—

Number of cultures and nature of parent plants in F_2	Segregations	Frequencies	
		Observed	Expected
10 cultures from plants with blue petals like F_1	Pure	2	1·1
	Like F_2 . . .	6	4·4
	3 blue : 1 lilac . .	2	2·2
	3 blue : 1 Type 12 .	0	2·2
6 cultures from purple plants like Type 121 .	Pure	1	2
	3 lilac : 1 white . .	5	4
8 cultures from plants with white petals .	Pure	8	8

The results of F_3 confirm those of F_2.

Filaments, styles and anthers. The F_1 has blue anthers ; filaments and styles and in F_2 these organs are blue in phenotypes with blue or lilac petals and white in the phenotype with white petals.

Stigma. Both parents have white stigmas and stigmas in all plants in this cross are white.

Seed. Both parents have brown seed and there is no segregation of seed colour in this cross.

Cross No. 10. Type 1 with Type 11.

Petals. The parents have already been described and as was expected, the F_1 of this cross had blue petals (Plate II). In F_2 the following phenotypic frequencies were observed :—

	Blue like F_1	Lilac like Type 11	White like Type 1	Pink	
1×11	107	39	32	8	=186
11×1	123	39	39	20	=221
Total observed . .	230	78	71	28	=407
„ expected . .	229·5	76·5	76·5	25·5	=408
Ratio observed . .	8·7	: 3·11	: 2·78	: 1·17	
„ expected . .	9	: 3	: 3	: 1	

X^2=0·651. The fit is good.

The pink phenotype appears as the double recessive as in the cross between Type 121 and Type 1.

In F_3 the following segregations were observed :—

Number of cultures and nature of parent plants	Segregations	Frequencies	
		Observed	Expected
5 cultures from plants with blue petals, like F_1 in F_2.	Pure	1	0·55
	Like F_2 . . .	1	2·2
	3 blue : 1 lilac Type 11 .	1	1·1
	3 blue : 1 Type 1 . .	2	1·1
3 cultures from plants with lilac petals like Type 11.	Pure	3	1·0
	3 lilac : 1 pink . .	0	2·0
4 cultures from plants with white petals like Type 1.	Pure	1	1·3
	3 Type 1 : 1 pink . .	3	2·6
4 cultures from plants with pink petals .	pure	4	4

The results of F_3 agree with those of F_2, but as only 16 cultures were raised in F_3 the divergence between observation and expectation is larger than it should be.

Filaments and anthers. The F_1 has blue anthers and in F_2 blue anthers occur in phenotypes with blue and lilac petals. In filament colour we find that all filaments are blue in F_1 and F_2 but that the restriction of the blue to the distal end of the filament, as in Type 11, is dominant. Observations in the cross 1×11 gave :—

	Blue filaments like Type 11	Blue filaments like Type 1	
Total observed	133	53	=186
„ expected	139·5	46·5	=186
Ratio observed	2·86 :	1·14	
„ expected	3 :	1	

Style. The style is blue in F_1 and in all individuals in F_2.

Stigma. The stigma in this cross is purple in F_1 and purple in all plants in the phenotypes with blue and lilac petals ; all plants in the Type 1 and pink phenotypes have pinkish white stigmas.

Seed. Type 1 has bold yellow seed and Type 11 has bold dark fawn seed. The F_1 has dark fawn seed and in F_2 we observed :—

Petal colour	Seed colour	Frequencies	
		Observed	Expected on 3 : 1
Blue like F_1	Dark Fawn	159	136·5
	Fawn	23	45·5
Lilac like Type 11	Dark Fawn	57	47·25
	Fawn	6	15·75
White like Type 1	Dark yellow	18	42·75
	Yellow	39	14·25
Pink	Dark yellow	11	18·75
	Yellow	14	6·25

In this cross we observed two grades of fawn colour in seed in phenotypes with blue or lilac petals and two grades of yellow in phenotypes with white and pink petals. On the basis of this observation, which was rendered more obvious by the linkage relationship between petal colour and seed colour, and from the fact that seed of Type 11 is a darker fawn than that of Type 8, the factor X was added to Type 11. In crosses Nos. 3 and 7 which were worked out before the cross between Types 1 and 11 was attempted, the distinction of grades of fawn was not, as already mentioned, noted. In this cross, however, there was no other contrast except that of fawn and yellow with the result that the differences in the grades of these colours were easily noted.

The total frequencies of all the fawns and all the yellows are :—

	Dark fawn and fawn	Dark yellow and yellow	
Observed	245	82	=327
Expected	245·25	81·75	=327

$$\frac{\text{Deviation}}{\text{Probable error}} = \frac{0{\cdot}25}{5{\cdot}28} = 0{\cdot}047.$$

giving a very close 3 : 1 fit with all fawn seeds in the phenotypes with blue or lilac petals. Similarly, considering all the seeds with darker tinge in contrast to the

lighter one, in the whole population, we again get a close approximation to 3 : 1 ratio as shown below :—

	Dark fawn and yellow	Light fawn and yellow	
Observed	245	82	=327
Expected	245·25	81·75	=327

When, however, we consider any one petal phenotype, the ratio of dark fawn to fawn or dark yellow to yellow departs widely from the 3 : 1 ratio, and if we set out the frequencies for seed colour and petal colour together, we obtain :—

	Blue or lilac petal, dark fawn seed	Blue or lilac petal, fawn seed	White Type 1 or pink petal, dark yellow seed	White Type 1 or pink petal, yellow seed
Observed	216	29	29	53
Expected on 9 : 3 : 3 : 1 .	183·87	61·29	61·29	20·43

These frequencies clearly indicate linkage between the factors D and X (page 48) both of which are present in Type 11. By calculation the cross-over value between D and X is determined to be about 20 per cent.

Cross No. 11. Type 1 with Type 22.

Petals. The F_1 of this cross was bright blue (Plate II) and in F_2 we observed the following phenotypes and frequencies :—

	Blue like F_1	Blue like Type 22	White like Type 1	White, non-crimped without veins	
22×1	55	19	17	5	=96
1×22	119	36	28	14	=197
Total observed . .	174	55	45	19	=293
,, expected . .	164·7	54·9	54·9	18·3	
Ratio observed . .	9·5	: 3·0	: 2·46	: 1·04	
,, expected . .	9	: 3	: 3	: 1	

X^2=2·24. The fit is satisfactory.

In F_3 the following segregations took place :—

Number of cultures and nature of parent plants in F_2	Segregations	Frequencies	
		Observed	Expected
12 cultures from plants with blue like F_1 petals in F_2.	Pure	2	1·3
	Like F_2 . . .	4	5·2
	3 blue : 1 Type 1 . .	4	2·6
	3 blue : 1 Type 22 .	2	2·6
3 cultures from plants like Type 22 . .	Pure	2	1·0
	3 Type 22 : 1 white .	1	2·0
3 cultures from plants like Type 1 . .	Pure	1	1·0
	3 Type 1 : 1 white .	2	2·0
4 cultures from white non-crimped plants .	Pure	4	4·0

The results of F_3 agree with F_2.

Filaments, styles and anthers. Blue anthers occur in F_1 and in all plants in F_2 in phenotypes with petals blue like F_1, or pale blue like Type 22. Blue styles occur in F_1 and in all plants with blue " like F_1 " petals in F_2. The segregation of colour in the filament in this cross was very difficult to observe. In the phenotype with petals blue " like F_1 " a few cases of white filaments are recorded, actually seven in the total population of 174, and no white filaments are recorded in the Type 1 phenotype. This indicates that the segregation of filament colour is dependent on the action of two factors, and that the cross shows blue and white filaments on a 15 : 1 ratio as follows :—

Petal colour	Filament Colour			
		Blue	White	Total
Blue like F_1	Observed .	167	7	174
	Expected .	163·15	10·85	174
White like Type 1	Observed .	45	0	45
	Expected .	42·2	2·8	45

The absence of any record of white filaments in the Type 1 phenotype is not a serious discrepancy in a population of this size (*i.e.*, 45) with a 15 : 1 ratio.

Stigma. The F_1 had a white stigma, and in F_2 we find purple stigmas in the phenotype with blue " like F_1 " petals :—

	White stigma	Purple stigma	
Observed	136	38	=174
Expected	130·5	43·5	=174
Ratio observed	3·13 :	0·87	
,, expected	3 :	1	
In the whole cross	255	38	=293
Expected on 13 : 3	238·1	54·9	=293
Ratio observed	13·92 :	2·08	

Seed. As regards seed colour the cross is the same as those between Type 1 and Type 12 and Type 1 and Type 121, and gives brown and fawn seeds in phenotypes with coloured petals and grey and yellow seeds in phenotypes with white petals.

In F_2 we observe :—

Petal colour	Seed colour	Frequencies	
		Observed	Expected
Blue like F_1	Brown	88	91·75
	Fawn	37	31·25
Blue like Type 22	Brown	34	31·5
	Fawn	8	10·5
White	Grey	33	33
	Yellow	11	11

	Brown	Fawn	Grey	Yellow	
Total observed	122	45	33	11	=211
,, expected	118·8	39·6	39·6	13·2	=211·2
Ratio observed	9·24 :	3·4 :	2·5 :	0·83	
,, expected	9 :	3 :	3 :	1	

The deficiency of grey and excess of fawn goes hand in hand with the deficiency of " White like Type 1 " and excess of " Blue like F_1 " in flower colour as grey seed colour is limited to the " White petal " and fawn is limited to " Blue like F_1 " and " Blue like Type 22 " petals.

Cross No. 12. Type 1 with Type 124.

Type 124 appeared as a mutation in Type 12 and differs from it only in seed colour.

Petals. As regards petal colour (Plate II) this cross is the same as that of Type 1 with Type 12 and in F_2 we observed :—

	Blue like F_1	White like Type 1	White like Type 124	White non-crimped	
1 × 124 (observed) . .	123	31	44	7	=205
Expected . . .	115·4	38·4	38·4	12·8	=205
Ratio observed . .	9·60 :	2·42 :	3·43 :	0·55	
„ expected . .	9 :	3 :	3 :	1	

There is a deficiency in the double recessive and a corresponding excess in Type 124. X^2=5·6 and the fit is not good but the population is small.

Filaments, styles and anthers. The inheritance of colour in anthers, filaments and styles agrees with that in Cross No. 1.

Stigma. In stigma, however, the F_1 is purple and in F_2 we observe that all plants in the phenotype with blue petals have purple stigmas.

Seed. The seed of Type 124 is yellow and so is that of Type 1. In F_1 the seed is fawn and we observed in F_2 :—

Petal colour	Seed colour	Frequencies	
		Observed	Expected
Blue like F_1	Fawn	75	78
	Yellow . . .	29	26
White like Type 124	Fawn	28	28·5
	Yellow . . .	10	9·5
White like Type 1	Yellow . . .	30	30
„ non-crimped	Yellow . . .	6	6

In the whole cross we observe :—

	Fawn	Yellow	
Observed	93	74	=167
Expected	93·94	73·06	=167

$$\frac{\text{Deviation}}{\text{Probable error}} = \frac{0{\cdot}94}{3{\cdot}77} = 0{\cdot}25.$$

Ratio observed	8·88 :	7·12	
„ expected	9 :	7	

III. Theory.

From the results of these 12 crosses we observe that blue colour in the petal depends on the interaction of several factors and that lilac colour in the petal is recessive to blue. Pink colour in the petal is recessive to lilac and to the Type 1 kind of white petal. Blue colour in the anthers, filaments and style, purple colour in the stigma and colour in the seed-coat are dependent on some of the factors which influence colour in the petal in addition to several other factors which determine the colour in these organs separately.

On the basis of the segregations observed in F_2 and F_3 we postulate the existence of the following factors which determine colour in the various parts of the flower and seed :—

B—a factor which acts with C to produce pink colour in the petals.

C—a factor for colour in the petals which acts with B to produce pink.

D—a factor which modifies pink colour in the petal to lilac. In the absence of B and the presence of E, D causes a faint tinge of blue in an otherwise white petal.

E—a factor which intensifies colour in the petal.

F—a factor which dilutes pink colour in the petal, so that in the presence of F lilac is modified to blue and pink is diluted to white with a pink tinge.

K—a factor which distributes the colour evenly all over the petal and also intensifies it when either E or F is present. In the absence of 'K', colour is deeper in the upper half of the petals, and becomes paler in the lower half. When E and F are both absent, K does not act as an intensification factor.

N—a factor which reduces the intensity of colour in the petal.

T—a factor which restricts blue colour in the filament to the distal region immediately below the anther.

Z_1—a factor which produces blue colour in the filaments if B, C and K and either E or F are also present.

Z_2—a factor which operates in the same way as Z_1 to produce blue in the filament. If either Z_1 or Z_2 is present, together with B, C, K and either E or F the filament is blue.

H—a factor which produces blue colour in the anthers when B and D are also present.

R—a factor which produces blue in the style if B, C, K and either E or F are also present.

P—a factor which produces pink colour in the stigma if B and C are also present. If in addition to these three factors D is also present the stigma is purple.

I—a factor which inhibits colour in the stigma.

G—a factor for grey colour in the seed-coat.

M—a factor which acts with D to produce fawn colour in the seed-coat ; if G is also present the fawn colour is converted to brown. In the absence of G, and if either M or D is also absent, the colour of the seed-coat is yellow

X—a factor which intensifies colour in the seed converting fawn to dark fawn and yellow to dark yellow.

On the basis of the functions performed by each of the above factors and from the results of the crosses we infer that the genetic constitution of the seven parental types is as follows :—

Type 1.—BBCCddEEFFKKNNttZ$_1$Z$_1$Z$_2$Z$_2$HHRRPPiiggMMxx
„ 8.—BBCCDDEEFFKKNNttZ$_1$Z$_1$z$_2$z$_2$HHRRppiiggMMxx
„ 11.—BBCCDDEEffKKnnTTZ$_1$Z$_1$z$_2$z$_2$HHRRPPiiggMMXX
„ 12.—bbCCDDEEFFKKNNttZ$_1$Z$_1$z$_2$z$_2$HHRRPPIIGGMMxx
„ 22.—BBCCDDeeFFkkNNttz$_1$z$_1$z$_2$z$_2$HHRRPPIIGGMMxx
„ 121.—BBCCDDEEffKKNNttZ$_1$Z$_1$Z$_2$Z$_2$HHRRPPIIGGMMxx
„ 124.—bbCCDDEEFFKKNNttZ$_1$Z$_1$z$_2$z$_2$HHRRPPiiggmmxx

IV. Application of Theory to the Observed Results.

We will now consider how this distribution of the factors agrees with the results obtained in F_2 and F_3.

Cross No. 1. This is between Types 12 and 1, and the F_1 is heterozygous for the factors B, D, I, Z_2 and G, the other factors being homozygous as given below :—

BbCCDdEEFFKKNNttZ$_1$Z$_1$Z$_2$z$_2$HHRRPPIiGgMMxx

As regards petal-colour we are dealing with a segregation of B and D and should expect that the F_1 would have a blue petal and that in F_2 we should obtain a population of the following phenotypic proportions :—

9 BD	3 bD	3 Bd	1 bd
Blue like F_1	White like Type 12	White like Type 1	White non-crimped

a result which agrees fairly closely with our observation (page 6). There is a deficiency in the frequency of the double recessive " white non-crimped " in F_2. This is possibly due to the gamete " bd " being produced by the F_1 plant less frequently than the other gametes ; some lethal action of the combination " bd " is indicated. At the same time the low frequency of the Blue : Type 12 segregation in F_3 suggests the zygote BDbD is in defect and indicates some lethal action of the combination bD. The evidence in favour of this view is discussed in Cross No. 12 (pages 49 and 50). Since both parents are homozygous for C, E, F, K, R and Z_1, blue colour in the filaments and style will occur in the F_1 and in those phenotypes in F_2 which contain B as is actually observed.

Since H is homozygous in both parents, blue colour in the anther will occur in the F_1 and in those phenotypes in F_2 which contain B and D (*i.e.*, in flowers with blue petals), as has been realized.

The stigma of F_1 is white, the factor I being heterozygous, and in F_2 we should expect the segregation of I to give a ratio of 3 white : 1 purple, as is actually observed.

As regards seed-colour there is a segregation of G and D in the presence of M and absence of X. We therefore expect a ratio in F_2 of—

9 GDMx	3 GdMx	3 gDMx	1 gdMx
Brown	Grey	Fawn	Yellow

with all the brown and fawn seed in plants with blue or Type 12 petals and all the grey and yellow seed in plants with petals like Type 1 or "non-crimped" white. This result is actually realized.

Cross No. 2. This is between Types 12 and 8, and the F_1 is heterozygous for the factors B, P, I and G, other factors being homozygous, as given below :—

BbCCDDEEFFKKNNttZ$_1$Z$_1$z$_2$z$_2$HHRRPpIiGgMMxx.

Considering petal-colour we are dealing with a segregation of B and should expect that the F_1 would have a blue petal and that in F_2 we should obtain a ratio of

BB	Bb		bb
1	2		1
3 blue like Type 8		:	1 white like Type 12,

a result which is closely realized. The evidence of F_3 confirms this theory.

The back-cross between the F_1 and Type 12 is of course a cross between Bb and bb and should result in a population of equal numbers of individuals with blue and white flowers, as is obtained. Since both parents are homozygous for C, D, E, F, K, Z$_1$, H and R, the inheritance of blue colour in anthers, filaments and style is determined by the segregation of B, and we should expect all plants, with blue petals, to have blue anthers, filaments and style, a result which is obtained.

With regard to stigma-colour we have a segregation of P and I as follows :—

F_1	P p I i	White stigma

F_2	9 P I	3 P i	3 p I	1 p i
	White	Purple	White	White

This gives a ratio of 3 purple : 13 white in F_2 in the phenotype with blue petals as has been actually realized (page 10). Since B is necessary for the development of purple colour in the stigma, this segregation only occurs in the phenotype with blue petals

and in this cross all plants with white petals must have a white stigma. In seed-colour factors both parents are homozygous for D, M and x and there is a segregation of G alone. This should give an F_1 with brown seed and a ratio of

GG	:	Gg	:	gg
1	:	2	:	1
3 brown				1 fawn

in F_2 as is realized.

Cross No. 3. The cross is between Type 12 and Type 11, and the F_1 is heterozygous for B, F, N, T, I, G and X, the other factors being homozygous, as follows :—

BbCCDDEEFfKKNnTt$Z_1Z_1z_2z_2$HHRRPPIiGgMMXx

In petal-colour we are dealing with a segregation of the factors B, F and N ; the F_1 should be blue and in F_2 we should expect.

27 B F N 9 B F n	9 B f N 3 B f n	9 b F N 3 b F n	3 b f N 1 b f n
36	12	12	4
Blue	Lilac	White	
9 :	3 .	4	

This result is realized in F_2 and supported by the observations in F_3, but unfortunately the segregation of N was not distinguished in the blue and lilac phenotypes, nor could any difference be seen between white-flowered plants of the Type 12 genotype (bFN) and the other three genotypes bfN, bFn and bfn.

Since both parents are homozygous for C, D, E, K, Z_1, H and R, the inheritance of blue colour in anthers, filaments and style will be determined by the segregation of B. We should expect blue colour in these organs in phenotypes with blue or lilac petals, and this is actually observed. In the case of filaments and styles the fact that F is heterozygous has no influence as E is always present. In the case of filaments, however, we have to consider the action of the factor " T " which restricts colour to the distal end of the filament as in Type 11. We should expect that the F_1 (Tt) would resemble Type 11 and that in F_2 we should obtain

T T	T t	t t
Type 11 filament	Intermediate classed with Type 11	Blue
1	2	1
3		1

This is realized in F_2 and in F_3.

Both parents are homozygous for P and we have to consider the segregation of I in those phenotypes which contain B and P. This should give in F_2 :—

II	Ii	ii
1	2	1
3 white		1 purple

—a ratio of 3 white to 1 purple stigma in phenotypes with blue or lilac petals. This is realized.

In seed-colour we are dealing with a segregation of G and X, since both parents are homozygous for D and M. The F_1 (GgXx) should have brown seed and in F_2 we should obtain :—

GX	G x	g X	g x
9	3	3	1
12 brown		3 dark fawn	1 light fawn
3 brown	:	1 fawn	

The 3 : 1 ratio is realized in F_2 but in this cross the distinction between dark fawn and light fawn seed was not noted. The evidence for the presence of X in Type 11 rests on the results of cross No. 10 between Type 1 and Type 11 ; this latter cross was not made until after the observations on the present cross were completed.

Had the results of the segregation of N and X been observed in the cross between Types 12 and 11 we should probably have observed linkage phenomena similar to those recorded for the cross between Types 121 and 11.

Cross No. 4. This is between Types 12 and 22, and the F_1 is heterozygous for B, E, K and Z_1, the other factors being homozygous as follows :—

BbCCDDEeFFKkNNttZ$_1$z$_1$z$_2$z$_2$HHRRPPIIGGMMxx

In petal-colour we are dealing with a segregation of B, E and K and should expect that the F_1 would have a blue petal and in F_2 we should expect :—

27 BEK	9 BEk	9 bEK	3 beK
9 BeK	3 Bek	3 bEk	1 bek
36 blue like F_1	12 blue like type 22	12 white like Type 12	4 white

The distinctive feature of Type 22 is its pale blue colour and the very light tint in the lower half of the petal, due to the absence of K. In the F_2 population in the blue phenotypes the genotypes which lack K appear like Type 22 whether E is present

or absent, the variation in the intensity of the blue colour due to the presence or absence of E being less marked than the restrictive effect of k. Similarly those blue phenotypes which possess K appear like the F_1 and the effect of the segregation of E cannot with certainty be distinguished.

Since both parents are homozygous for D and H, the occurrence of blue colour in the anthers is determined by the segregation of B and we actually observe that anthers are blue in all flowers with petals "blue like F_1" or like Type 22.

In the case of filaments we observe that F_1 has blue filaments and that in F_2 there is a 3 : 1 ratio of blue to white in the phenotype with petals blue "like F_1" and that filaments are white in all other phenotypes. The factors B, C, K and Z_1 and either E or F are necessary for blue colour in the filaments and of these both parents are homozygous for C and F. The segregation of B, K and Z_1 should give a ratio of 27 blue to 37 white in the whole cross with a ratio of 3 blue to 1 white in the phenotype which contains B and K, *i.e.*, petals blue "like F_1".

27 Z_1BK	$9z_1$BK	9 Z_1Bk	9 Z_1bK	3 z_1Bk	3 Z_1bk	3z_1bK	1 $z_1$bk
	Blue filaments			White filaments			
	Blue like F_1 petals			White petals			

This result is closely realized.

Both parents are homozygous for C, F and R, hence the occurrence of blue colour in the style will be determined by the presence of B and K ; that is, all flowers with petals blue "like F_1" should have blue styles and this is actually observed.

Since I is homozygous in both parents there should be no purple colour in any stigmas in this cross ; this is realized. Similarly, since both parents are homozygous for D, G, M and x there is no segregation of seed-colour.

Cross No. 5. This cross is between Type 121 and Type 1 and the F_1 is heterozygous for D, F, I and G and homozygous for all other factors as follows :—

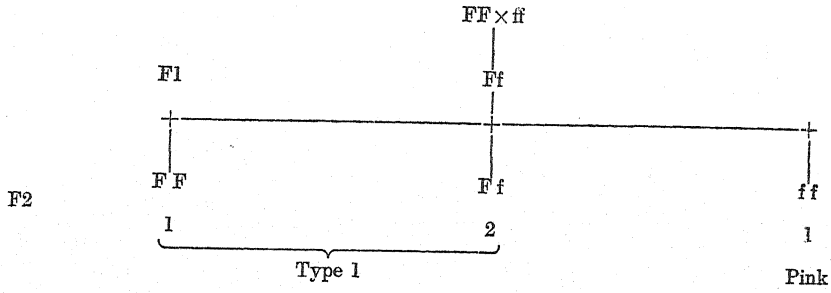
BBCCDdEEFfKKNNtt$Z_1Z_1Z_2Z_2$HHRRPPIiGgMMxx

As regards petal-colour we are dealing with a segregation of D and F and should expect that the F_1 would have a blue petal and that in F_2 a dihybrid segregation of

9 DF	3 Df	3 dF	1 df
Blue	Lilac	White like Type 1	Pink

would result. This is closely realized in F_2 and F_3, and a cross between the new phenotype, pink, and Type 1 resulted in an F_1 like Type 1 and a ratio of 3 Type 1 to

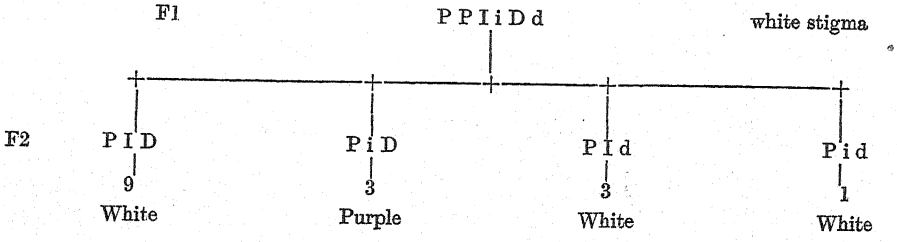
1 pink in F_2, clearly establishing a monohybrid difference between pink and Type 1. This cross, of course, is



Since both parents are homozygous for B and H, the colour of anthers should be determined by the segregation of D and should give blue anthers in phenotypes with blue or lilac petals ; this is realized.

Both parents have blue filaments and are homozygous for B, C, E, K and Z_1 and Z_2 ; there is, therefore, no segregation in filament-colour in this cross. Since also, in addition to the above, R is homozygous throughout the cross, all styles are blue.

Type 1 has a pink stigma since B and P are present and D is absent. Type 121 has a white stigma since in addition to P, it also carries I. The F_1 has a white stigma and the cross is



This gives a ratio of 3 purple to 13 white in the whole cross and actually we observed :—

	Purple	White	
Observed	56	258	=314
Expected	58·95	255·05	=314

with all the purple stigmas in phenotypes with blue or lilac petals, which contain D. In phenotypes with blue or lilac petals we should expect the segregation of I to give a ratio of 3 white stigma to 1 purple stigma as is actually observed.

As regards seed-colour in this cross, the F_1 has brown seeds and is GgDdMMxx, we have, therefore, a segregation of G and D in the presence of M and x. This is the same as the cross of Type 12 and Type 1 and a comparison of the two crosses shows that the same result is realized, all the brown and fawn seeds occurring in phenotypes with blue or lilac petals and all the grey and yellow seeds occurring in phenotypes with petals white like Type " 1 " or pink.

Cross No. 6. The cross is between Types 121 and 8 and the F_1 is heterozygous for F, Z_2, P, I and G, and homozygous for all other factors as follows :—

BBCCDDEEFfKKNNttZ$_1$Z$_1$Z$_2$z$_2$HHRRPpIiGgMMxx

In petal-colour the segregation of F should give a blue F_1 and a ratio of 3 blue : 1 lilac in F_2 as is exactly realized.

Since both parents are homozygous for B, C, D, E, K, H, R and Z_1, we should expect all anthers, styles and filaments to be blue in this cross and this is actually the case.

In stigma-colour we should expect the action of P and I to give a white stigma in F_1 and a ratio of 3 purple to 13 white in F_2. This is fairly closely realized and is supported by the evidence of F_3. As regards stigma-colour this cross is exactly the same as that between Types 12 and 8, with the exception that, since Types 121 and 8 are both homozygous for B and D, the purple stigmas are not restricted to any one petal phenotype.

In seed-colour we have a segregation of G in the presence of D, M and x as in cross No. 2 and the result is exactly the same.

Cross No. 7. The cross is between Types 121 and 11, and the F_1 is heterozygous for N, T, Z_2, I, G and X, all other factors being homozygous as follows :—

BBCCDDEEffKKNnTtZ$_1$Z$_1$Z$_2$z$_2$HHRRPPIiGgMMXx.

As regards petal-colour the segregation of the reduction factor N should give an F_1 resembling Type 121 and an F_2 in which the Type 121 petal is dominant to the Type 11 petal on a 3 : 1 ratio. This is actually found.

Both parents being homozygous for B, D, C, E, K, Z_1, H and R, the anthers, filaments and styles are blue throughout the cross. In the case of filaments the segregation of the restriction factor T should give an F_2 population with the Type 11 type of filament dominant on a 3 : 1 ratio ; this is realized.

In stigma-colour the segregation of I should result in white stigmas in F_1 and in white stigmas being dominant to purple in F_2 on a 3 : 1 ratio ; observed frequencies agree with this. Linkage between purple colour in the stigma and deep lilac (like Type 11) in the petal is suggested by the fact that in F_2 these characters occur in the parental combinations with a greater frequency than would be expected on a 9 : 3 : 3 : 1 ratio. The linkage is between factors N and I and the formula of the F_1 as regards

the heterozygous factors for colour in petal and stigma may then be written NnIi giving gametes :—

NI	Ni	nI	ni
Petal Type 121 and stigma white	Petal Type 121 stigma purple like Type 11	Petal Type 11 stigma white like Type 121	Petal Type 11 and stigma purple like Type 11

For a cross-over value of 14 per cent. these gametes will be produced by the F_1 plant in the approximate proportions—

6 NI : 1 Ni : 1 nI : 6 ni

A back-cross between the F_1 plant and Type 11 gave the following frequencies :—

Petal Type 121, Stigma white	Petal Type 121, Stigma purple	Petal Type 11, Stigma white	Petal Type 11, Stigma purple
21	4	5	32

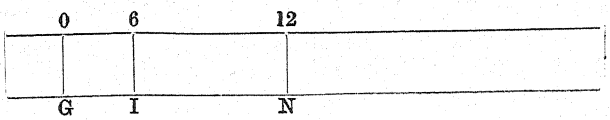
The parental types are roughly six times as numerous as the other two phenotypes (*i.e.*, 53 : 9), if there were no linkage all four phenotypes would occur in equal numbers.

The factors G and X are heterozygous in this cross and we should expect a segregation of brown, dark fawn, and light fawn colour in the seed in F_2 as in cross No. 3. Moreover, this segregation should be independent in each phenotype for petal colour. Actually while the proportion of brown seed to fawn agrees with a 3 : 1 ratio in the whole cross we find that this ratio is not realized in each petal phenotype ; brown seeds are in excess with the petal phenotype like Type 121 and fawn seeds are in excess with the Type 11 phenotype. In other words, the parental combinations are more numerous than they should be on independent segregation and there is linkage between N and G. The cross-over value in this case is 15 per cent.

When once the linkage between the petal-colour factor (N) and the stigma-colour factor (I) and that between the petal-colour factor (N) and the seed-colour factor (G) was established, it was natural to expect a linkage between stigma-colour and seed-colour as well, which was not noticed till then. On looking to the records we actually found that there is also a linkage between stigma-colour and seed-colour, *i.e.*, between factors G and I.

The next question arises as to the location of the factors on the chromosome. On the basis of the linear arrangement of factors as established by Morgan and his colleagues, we expect that the factors G and I should either be very close to one another (*i.e.*, they should give a much lower cross-over value than that given by N and I or N and G) or fairly wide apart (*i.e.*, the cross-over value for this should nearly be equal to the sum of the cross-over values obtained for the N and I linkage and N and G linkage).

This is again realized fairly closely and we actually find that the cross-over value for G and I is about 9 per cent., *i.e.*, much less than was obtained for G and N or N and I. This value of 9 per cent. is, however, much more than what should be expected considering the small difference between the cross-over values for N-I and N-G. But this deviation may be accounted for when we consider that one of the characters that we are dealing with (*i.e.*, intensity of petal colour) is a somewhat fluctuating character ; a few of the individuals placed in the light petal class may actually belong to dark petal class and *vice versâ*. Even slight errors in the classification of phenotypes in F_2 would have appreciable effect in working out the linkage relationships. We may further note that the total population of the cross under consideration is not quite enough for working out definite cross-over values. In such a study a population of even 5,000 is not too much, while our population is confined to only 352. We may not be very wrong in assuming that the 15 per cent. cross-over value for the linkage between N and G may actually vary from 15 to 20 per cent. and the 14 per cent. for N and I may vary from 10 to 15 per cent. while the 9 per cent. for G and I may vary from 5 to 10 per cent. These values would then establish the respective position of these three factors on the same chromosome as depicted below :—



Cross No. 8. The cross is between Types 121 and 22, and the F_1 is heterozygous for E, F, K, Z_1 and Z_2 and has the formula :—

BBCCDDEeFfKkNNttZ$_1$z$_1$Z$_2$z$_2$HHRRPPIIGGMMxx

The result of the segregation of E, F and K will be :—

27 EFK	Blue like F_1.
9 eFK	Blue like F_1 but lighter.
9 EFk	Blue like Type 22 but deeper.
9 EfK	Lilac like Type 121.
3 eFk	Blue like Type 22.
3 efK	Pale lilac.
3 Efk	Lilac limited.
1 efk	Pale lilac limited.

It has already been mentioned that the variation of the intensity of colour in the petal with the time of observation and the intensity of sunlight is such as to obscure the result of the segregation of E and the phenotypes observed probably consist of the following genotypes :—

Blue like F_1	Lilac like Type 121	Pale blue like Type 22	Pale lilac
27 EFK	9 EfK	3 EFk	3 Efk
9 eFK		9 eFk	3 efK
			1 efk
36 :	9 :	19	

Comparing this with the results of cross No. 4 between Types 12 and 22, we see that the difficulty here is that the phenotype which resembles the Type 22 is difficult to distinguish from those lilac genotypes which lack either K or E and hence are not of the Type 121 genotype. This is due to the fact that pale lilac and pale blue appear very similar especially when both have faded slightly, whereas in Cross No. 4 there was no danger of confusing the white phenotype, resembling Type 12, with that resembling Type 22. On the ratio 36 : 9 : 19 a much closer fit between expectation and observation is realized than with the 9 : 3 : 4 ratio, page 26) :—

	Blue like F_1	Lilac like Type 121	Blue like Type 22	Pale lilac	
Observed	211	63		121	=395
Expected	222·2	55·55		117·26	=395·01
	$X^2=1·666$				
Observed	95	29		51	=175
Expected	98·44	24·61		51·95	=175

X^2 is less than 1 and the fit is excellent.

The fit is fairly close. The phenotype " eFK " appears blue on account of the presence of K which acts both as an intensifier and a distributor of colour, while " EFk " will be classed as " pale blue " as the restriction of colour to the upper half of the petals is more remarkable than the intensity of the colour which varies considerably with the age of the flower and the time of the day. Moreover, in the absence of K, on our theory, the intensity of colour is also reduced.

The phenotype efK is classed as pale lilac because K is functionless as an intensifier when both E and F are absent.

The F_2 observations agree with this segregation of 36 : 9 : 19 fairly closely and the greatest support to this is obtained from F_3 segregations where amongst the cultures with blue flowers in F_2, a high proportion of cultures segregating like F_2 and those segregating into blue and pale blue is in absolute conformity with this segregation,

while it deviates appreciably from an ordinary dihybrid segregation as would appear from the statement given below :—

Segregation	Observed	Frequencies	
		Expected on 9 : 3 : 3 : 1	Expected on 36 : 9 : 19
Pure blue	0	0·78	0·78
3 Blue : 1 lilac	1	1·56	0·78
3 Blue : 1 pale blue	2	1·56	1·56
Like F_2	4	3·10	3·88

It is a pity the F_3 cultures were so few in this cross, otherwise we might have got more definite results.

A word about the summing up of the last two classes, *i.e.*, pale blue and pale lilac. The two phenotypes with pale blue colour are not easily distinguishable from the 3 phenotypes with pale lilac colour. In F_2 we attempted to classify them but the differences were so minute that we have combined the two classes into one for all practical purposes. This confusion is most probably due to the variable development of colour in different degrees of sunlight and in particular to the changes which take place the longer a flower has been open. Flowers open at about 9 A.M. and on a sunny day by noon the colour has faded very much in blue and lilac petals ; Type 22 in particular tends to become almost white with a lilac tinge rather than a blue tinge. For this reason the attempt to separate Type 22 from the recessive was abandoned.

It may further be noted here that the F_2 frequencies show a slight excess of lilac and corresponding deficiency of blues. Probably some of the blues were wrongly diagnosed as lilacs. Such mistakes are quite liable to occur when hundreds of plants have to be examined at a stretch. Actually the lilac flax is nothing but a blue with some additional " pink " in it.

Since both parents are homozygous for B, D, and H we should expect blue anthers throughout the cross and this is realized. Both parents are homozygous for B and C and colour in the filaments will be determined by the segregation of E, F, K, Z_1 and Z_2. Since K and either E or F are necessary for colour in the filament, blue filaments will only occur in phenotypes with petals " blue like F_1 " or lilac, and we should obtain from the segregation of Z_1 and Z_2 in these phenotypes :—

$$\underbrace{\underset{9}{Z_1Z_2} \quad \underset{3}{Z_1z_2} \quad \underset{3}{z_1Z_2}}_{\text{15 blue filaments}} \quad : \quad \underset{1}{z_1z_2} \qquad \text{1 white filaments}$$

—a result which is realized.

Both parents are homozygous for B, C and R and we should expect blue styles to occur in those genotypes which contain K and either E or F. This is realized and blue styles are present in all plants with petals " blue like F_1 " or lilac.

Both parents being homozygous for I we should not obtain purple stigmas in this cross and they are not observed. Similarly G, M, x and D being homozygous, all the seed in the cross should be brown, as is found.

Cross No. 9. The cross is between Types 121 and 12, and the F_1 is heterozygous for B, F and Z_2 and has the formula—

BbCCDDEEFfKKNNttZ$_1$Z$_1$Z$_2$z$_2$HHRRPPIIGGMMxx

In petal-colour we should expect F_1 to be blue and F_2 to show :—

BF	Bf	bF	bf
9	3	3	1
Blue like F_1	Lilac like Type 121	White like Type 12	White
9	3	4	

This result is realized in F_2 and in F_3

Since both parents are homozygous for C, D, E, K, Z_1, H and R we should expect colour in anthers, filaments and style to be determined by the segregation of B, a result which is actually observed, blue colour in these organs being present in all plants with blue and lilac petals.

Since I is homozygous, all stigmas in this cross should be white, and since G, M, x and D are homozygous, all seeds should be brown. The observations agree with this theory.

Cross No. 10. The cross is between Types 1 and 11, and the F_1 is heterozygous for D, F, N, T, Z_2 and X and has the formula

BBCCDdEEFfKKNnTtZ$_1$Z$_1$Z$_2$z$_2$HHRRPPiiggMMXx.

In petal-colour we should expect the F_1 to be blue and in F_2

27 DFN	9 DfN	9 dFN	3 dfN
9 DFn	3 Dfn	3 dFn	1 dfn
36 blue	12 lilac	12 like Type 1	4 pink

In each phenotype the segregation of N should give two grades of colour. This was not distingusihed at the time in blue and lilac phenotypes but two grades of pink were seen. A 9 : 3 : 3 : 1 ratio was realized in F_2. This cross resembies cross No. 5 and gives pink as the double recessive.

Both parents are homozygous for B and H, therefore anthers should be blue in F_1 and in F_2 the occurrence of blue colour in anthers will be determined by the segregation of D ; this is realized, all plants with blue or lilac petals having blue anthers.

Filaments are blue throughout the cross since B, C, E, K, and Z_1 are homozygous. The fact that Z_2 is heterozygous in F_1 does not have any result, as Z_1, by itself, is sufficient to produce colour in filaments. The segregation of T should make the Type 11 type of filament dominant and this is observed. Since both parents are also homozygous for R and K, styles are blue throughout the cross.

Both parents are homozygous for P and i ; the stigma should therefore be purple in F_1 and purple in those phenotypes with blue or lilac petals which contain D. This is realized in F_2.

Type 1 has bold yellow seed and Type 11 bold dark fawn. The cross is

ddggMMxx x DDggMMXX

and we are dealing with a segregation of D and X in the presence of g and M. This should give in F_2

Petals blue or lilac		Petals Type 1 or pink	
9 DX	3 Dx	3 dX	1 dx
dark fawn	fawn	dark yellow	yellow

with all the fawn seed in the phenotypes with blue or lilac petals and all the yellow seed in phenotypes with petals like Type 1 or pink. In the whole cross the ratio of all plants with fawn seed to all plants with yellow seed should be 3 : 1. This is realized in F_2 but considering the frequencies for seed-colour in each petal phenotype separately there is a wide departure from the theoretical 3 : 1 ratio. Combining the frequencies for petal-colour and seed-colour we note that the dark grade of seed-colour is in great excess in the phenotypes with blue or lilac petals and the light grade is in excess in phenotypes with petals like Type 1 or pink. The plants with blue or lilac petals are of course in a 3 : 1 ratio to the total of those with Type 1 or pink petals. There is, we infer, linkage between D and X and the cross-over value is calculated at about 18 per cent.

Cross No. 11. The cross is between Types 1 and 22, and the F_1 is heterozygous for D, E, K, Z_1, Z_2, I and G and has the formula :—

BBCCDdEeFFKkNNttZ$_1$z$_1$Z$_2$z$_2$HHRRPPIiGgMMxx.

The F_1 has a blue petal and in F_2 we expect

Blue like F_1		Pale blue like Type 22		White like Type 1		White non-crimped
27 EDK		9 EDk		9 EdK		3 Edk
9 eDK		3 eDk		3 edK		1 edk
36	:	12	:	12	:	4

a ratio which is realized. As in the previous crosses with Type 22 the segregation of K, in combination with the other factors, is decisive in determining the frequency of the Type 22 phenotype.

Both parents are homozygous for H and B and, therefore, the distribution of blue colour in the anther is determined by the segregation of D, and we actually find in F_2 that blue anthers are present in all plants with petals " blue like F_1 " or blue like Type 22.

In the case of filaments Type 1 is homozygous for B, C, E, F, K, Z_1 and Z_2, while Type 22 contains only B, C and F. Since F is homozygous in both parents we can disregard E and have only to consider the segregation of Z_1 and Z_2 in the presence of B, C and F and K. This means that blue filaments can only occur in phenotypes with petals " blue like F_1 " or " white like Type 1", and that blue filaments will be dominant in these phenotypes on a 15 : 1 ratio.

Z_1Z_2	Z_1z_2	z_1Z_2	z_1z_2
9	3	3	1
15 blue			1 white

This has been realized in the phenotype with petals " blue like F_1 "; the non-occurrence of white filaments in the phenotype " white like Type 1 " is not a serious discrepancy as the population in this class is small and we expect only 2·8 plants with white filaments in this class.

Since both parents are homozygous for B, C, F and R, the occurrence of blue styles will be determined by the segregation of K and we should expect blue styles in all plants with petals blue like F_1 or white like Type 1. This is actually found.

In stigma-colour we are dealing with a segregation of I and D in the presence of P as in Cross No. 5. This should give a ratio of 1 purple to 3 white stigmas in the phenotype with petals " blue like F_1 " and a ratio of 3 : 13 in the whole cross, as is realized.

Seed-colour is determined by the segregation of D and G as in Cross No. 5. We should expect the same result and this is realized.

Cross No. 12. The cross is between Types 1 and 124. Type 124 arose in a culture of Type 12 and differs from it only in possessing yellow seed. The F_1 is heterozygous for B, D, Z_2, G and M and has the formula

BbCCDdEEFFKKNNtt$Z_1Z_1Z_2z_2$HHRRPPiiggMmxx.

In petal-colour the inheritance is the same as in the cross of Type 12 and Type 1. There is the same deficiency of the white double recessive. Some light is thrown on this by a cross between the F_1 of this cross and Type 12. The gamete of Type 12 is bD and the gametes of the F_1 of Type 1 × Type 124 are BD, Bd, bD, and bd. The results of the cross should be the production of the 4 zygotes :—

BDbD	BdbD	bDbD	bdbD
Blue	Blue	White	White

in equal numbers. Actually instead of equal numbers of plants with blue and plants with white petals we obtained a population of 41 blues and 19 whites. The deficiency in the whites should be considered in relation to the deficiency of the double recessive " bdbd " in the cross Type 1 × Type 124 and in the cross Type 1 × Type 12. It is suggested that the gamete " bd " in the F_1 of both these crosses is less viable than the other gametes and produces a living zygote less frequently than the other combinations. The deficiency of the whites in the cross between Type 12 and the F_1 of Type 1 × Type 124 would, in this case, be due to a deficiency of the zygote " bdbD ". If, however, we attribute the deficiency in the white-flowered plants entirely to the zygote " bdbD " all the burden of the discrepancy is thrown on the gamete " bd " of F_1. This point of view should lead to a serious distortion of the frequencies in F_2 ; a result which has not been observed. The fact that both in Cross No. 1 and Cross No. 12 in F_2 the Type 12 phenotype is not in defect does not suggest any lethal action in the combination " bdbD " ; on the other hand, the low frequency of the segregation Blue : Type 12 in the F_2 of Cross No. 1 does suggest that the xygote " BDbD " is in defect in F_2 and that this is due to some defect in the gamete " bD ". Possibly both the gametes " bD " and " bd " tend to form non-viable zygotes, this tendency being more marked in the combination " bd ". The F_1 was also crossed with Type 8, the gamete of which is " BD " and the resulting progeny consisted of plants all of which had blue petals—this is in accordance with expectation.

The inheritance of colour in anthers, filaments and styles is, of course, the same as in Cross No. 1.

Both parents have a white stigma since although each is homozygous for i and P both lack one of the other factors, B or D, for stigma-colour. The F_1, however, which receives both B and D has a purple stigma and stigmas are purple in F_2 in the phenotype with blue petals. We infer that Type 124 has lost the factor I, and, therefore, both parents are homozygous for i, and the stigma is purple in F_1 and in the blue petal phenotypes of F_2 owing to the presence of B, D and P. In the whole cross, therefore, we have purple stigmas 123, white stigmas 82, which approximates to a 9 : 7 ratio.

The seed of Type 124 is yellow and from the results of this cross we infer that Type 124 differs from Type 12 in having lost the factors G and M. The cross between Type 1 and Type 124 is, therefore,

Type 1		Type 124
dgMx	x	Dgmx

and the F_1 is DdggMmxx.

The segregation of D and M should give in F_2 a ratio of 9 fawn to 7 yellow in the whole cross and a ratio of 3 fawn : 1 yellow in those phenotypes, blue and Type 124 which contain D. Phenotypes which lack D, Type 1 and the noncrimped, will have all seed yellow. This is realized.

V. Discussion of Results.

According to Tammes, the colour of the petal depends upon the interaction of eight hereditary factors—A, B_1, B_2, C, D, E, F and K. Three of these factors B_1, B_2 and C are basal factors for colour and must be present if any colour is to occur, two factors, D and F, influence the tint of the colour, and two others, A and E, determine its intensity, while a factor K controls the distribution of the colour in the petal. To these eight factors, on the evidence of the crosses described in this paper a ninth factor N, which reduces the intensity of the colour must be added, nor does it appear necessary to postulate three basal factors, according to our evidence two, B and C, are sufficient. The intensification factor A also appears to be unnecessary. It is quite probable that what Tammes calls intensification factor " A " is really the reduction factor " N ". Tammes possibly tried to classify the lightest blues and lilacs in contrast to the rest, thus giving a ratio of 3 dark blues or purple : 1 light blue or purple but our evidence shows definitely that the dark petal colour is recessive to the light giving a ratio of 1 : 3 : : dark : light. On this evidence we have put a reduction factor " N " which reduces the dark tinge to light. So far as the petal-colour is concerned, our theory does not differ materially from that of Tammes. The main difference is in the action of the factor " D " which produces in the presence of E a faint blue tinge in the petal even when one of the fundamental factors " B " is absent (see Type 12). It appears, therefore, somewhat of a misnomer to term B and C basal factors for colour, when in the absence of one a faint blue tinge is produced. We may consider them as basal factors for " pink colour " which in turn is essential for full development of blue and purple colour in the petal, but a faint blue tinge can be produced even in the absence of one of them. On the evidence of the cross No. 8 (Types 1 × 22) we have slightly modified the function of the factor " K ", which appears to be not only distributing the colour all over the petal evenly, but also intensifying the colour to some extent in the presence of E or F. In case both E and F are absent, K alone cannot intensify the colour.

Considering the shape of the petal we have found considerable amount of variation in this character from type to type, *e.g.*, Type 1 has broad and large petals, while Type 11 has much narrower petals, so that it appears elongated in shape.

In both these types and in most others the petals are smooth and open well, but in Type 12 and Type 124 (which is a mutant from Type 12) the petals do not open well and present a crimped appearance. While the inheritance of broad and narrow petals is probably determined by quantitative factors, the occurrence of this type of petal (*i.e.*, crimped) is dependent on the interaction of two or more qualitative factors which determine the petal colour as well and hence its study is of special interest.

Our observations as regards the inheritance of crimped petals point to a different state of affairs from that investigated by Tammes. She considers that " C " causes

the deviating (*i.e.*, crimped) shape but does not do so when B_1 and B_2 are both present or in the presence of D—a view which is not supported by our results. We disagree with Tammes in so far as the action of the factor B is concerned and the action of D is just the reverse of that stated by this author. According to Tammes D checks the appearance of the deviating (*i.e.*, crimped) shape, while we consider that both D and E are responsible for bringing about the deviating shape. In the absence of either of them, even when "B" is absent, the deviating, *i.e.*, "crimped" shape occurs.

This is borne out by the results of the crosses with Type 12. The formula (considering the factors B, C, D, E and F alone) of the recessive in all such crosses and the nature of the shape of petal is given below :—

Cross No. 1	12 × 1	bCdEF	Non-crimped
„ „ 2	12 × 8	bCDEF	Crimped
„ „ 3	12 × 11	bCDEf	„
„ „ 4	12 × 22	bCDeF	Non-crimped
„ „ 9	12 × 121	bCDEf	Crimped
„ „ 11	1 × 22	BCdE / BCde	Non-crimped

According to Tammes the recessives in the crosses Nos. 2, 3 and 9 should be non-crimped as D is present in them, while the recessive in cross No. 1 should be crimped as both B and D are absent in this but actually we find just the reverse.

From the above it is evident that the crimped petals occur only when C, D and E are all present. Actually we cannot make any one of them absolutely responsible for the production of the crimped appearance. It may be the result of the interaction of all the 3 factors. Whenever any one of these three factors is absent we get non-crimped petals. We agree with Tammes in the action of B, *i.e.*, that the crimped petals do not occur when B is present irrespective of the presence or absence of all other factors, the evidence of Cross No. 11 on this point is conclusive.

From the above consideration we conclude that the "crimped" petals are caused by the interaction of the factors C, D, and E only, when B is absent. In the presence of B, or when any one of the 3 factors C, D and E is absent, we get non-crimped petals.

The colour of the seed is according to Tammes determined by the interaction of a factor G with the factors B_1 and D. Tammes states "with respect to this character it has also appeared that some of the factors are involved which also determine the colour of the flower. If the basal-factor G, necessary for the formation of the colour of the seed, is present and likewise the factors B_1 and D,

the seed shows one of the colours from a series of light-yellow, dark-yellow, brownish-yellow, yellowish-brown, dark brown to black-brown. If the factor B_1 is lacking the different colours also form a series from light to dark, but in all except in the light-yellow ones the tint is more or less greenish. If D or both D and B_1 are lacking there also occurs a whole series of light to dark seed types, which except the light-yellow ones, all show a more or less brown tint. This brown tint, however, is distinguished from that of the first mentioned series by its being more greyish-brown and never mahogany-or ruddy-brown as occurs in the others. Yet especially in the types of average intensity it is sometimes very difficult to decide to which of the two groups a certain seed belongs". On the evidence of this paper we suggest a modification of this theory of seed colour and our study shows more definite results. We distinguish four colours in the seed—brown, grey, fawn and yellow.

We do not agree with Tammes in assuming that no colour in the seed coat is produced unless a basal factor G is present. As we have evidence on record that in the absence of G we get a colour in seed coat, which we have called "fawn" and that this colour is produced by a factor M in presence of D. When either of them or both are absent we get the basic yellow colour, which may really be the cotyledon colour seen through the transparent, colourless seed-coat, as suggested by Tammes. But it is more probable, especially on the basis of the action of the intensification factor X (which turns basic yellow to dark yellow), that the basic colour of seed coat is yellow, which is itself the result of the action of another factor.

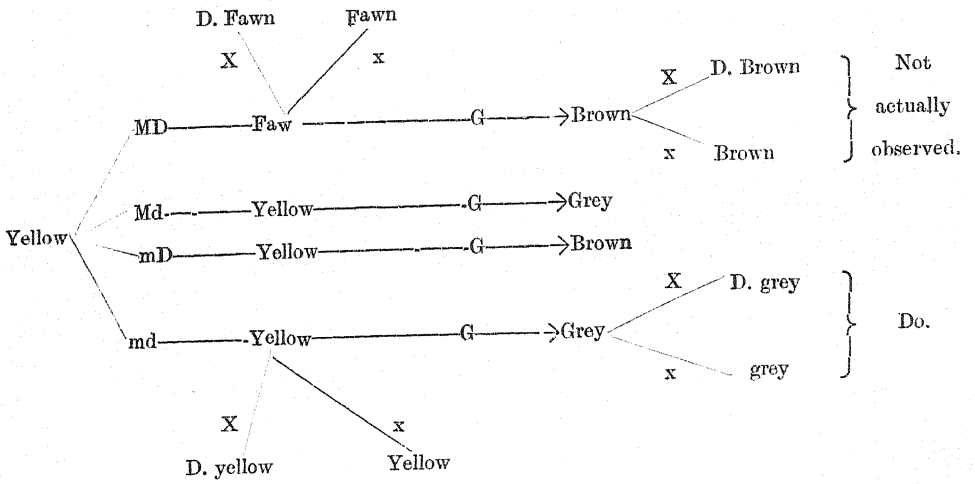
In the presence of G alone, or even when M is present, the seed colour is grey. If the petal colour factor "D" is also present, this grey is converted into brown.

On our evidence we do not find the factor "B" to influence seed colour in any way. Type 12 lacks the factor "B" but it possesses as brown a seed as Type 121 or Type 22 which possess this factor. It may be that our factor "B" corresponds to the "B_2" of Tammes. So far we, however, have no evidence to split the factor B into B_1 and B_2.

In addition to these factors we find that seed colour is also influenced by another factor X which is linked with the flower colour factor "D". The action of factor X is to produce a darker tinge in seed colour. It probably acts in all the seed-colour phenotypes, but the dark and light grades are not easily classifiable except in fawn and yellow phenotypes.

Thus summarising the action of the factors influencing seed-colour we find that the basal colour of the seed-coat is yellow. It is transformed into fawn, if both the factors M and D are present, while if only one of them is present, the colour still remains yellow. In presence of an additional factor G this fawn colour changes to brown. In absence of D and presence of G the seed coat colour is grey irrespective of the presence or absence of M. Factor X only intensifies the

already existing colour. Its action is most pronounced in fawn and yellow phenotypes. The whole process is diagrammatically illustrated below :—



Finally it may be noted that since D is also a factor for petal-colour the distribution of the various phenotypes of seed-colour among the phenotypes of petal-colour affords a ready proof of the theory. We actually find that the brown and fawn colour in the seed occurs, in all the crosses, only in phenotypes which contain the factor D.

The inheritance of blue colour in the anther depends on the action of a factor H with the two factors B and D which determine petal-colour. This theory is the same as that advanced by Tammes.

As already pointed out in the introduction, we had great difficulties in noting colour in filaments, style and stigma which has not so far been attempted by any previous investigator. But inspite of all these difficulties we have been able to postulate a fairly tangible theory that explains the segregation of colour in filaments, style and stigmas in these crosses.

We find that the expression of colour in filaments is dependent on three distinct mendelian factors one of which (*i.e.*, T) is an inhibitory factor and the other two (*i.e.*, Z_1 and Z_2) are duplicate factors either of which can produce colour in filaments. In addition to these some of the petal colour factors are also essential for the development of any colour in filaments. These factors are B, C, K and either E or F. If any of the factors B, C or K is absent and if neither E or F is present, the filaments remain white even if the fundamental factors Z_1 and Z_2 are present. The evidence for the occurrence of the duplicate factor is derived from the crosses with Type 22 which lacks both the factors Z_1 and Z_2, while the Types 1 and 121

appear to possess both these factors as their crosses with Type 22 show the segregation of filament colour as 15 blue : 1 white. On the other hand, the cross between Type 12 and Type 22 gives a definite 3 : 1 ratio of blue : white filaments, thereby indicating that Type 12 possesses only one of these duplicate factors.

The factor T, which restricts the blue colour in the filaments to the distal end, occurs only in Type 11 ; all other types are without it.

The style colour is apparently determined by some of the factors that determine petal colour, *i.e.*, B, C, K and either E or F as in the case of filaments. If any one of the factors B, C, and K is absent and if neither E or F is present the style-colour is white. But it is quite probable that there may be a separate factor for the development of colour in styles as well and that all the types considered in this paper are homozygous for that factor. On this assumption we have put a factor R which produces colour in style in presence of B, C and K with either E or F. This factor is present in all the types under consideration.

The stigma-colour is determined by a factor P which produces pink colour in stigma if the factors B and C are also present. If in addition to these three factors, D is also present, the stigma-colour is purple as noticed in Type 11. This factor is present in all our types except Type 8. But the actual segregation of stigma-colour is not so simple as indicated above. There is still another factor I which is also involved in our crosses. It inhibits the development of colour in stigma thereby making it to appear white even when B, C, D and P are all present.

It will be noticed in the formulæ of the types that factor C is homozygous and present in all the types. This would suggest that this factor is unnecessary—we have, however, retained it as we possess evidence from some other crosses, which are still under investigation, that some types with white petals do not possess this factor. The same reason accounts for the presence of H and R in the homozygous condition in all the types investigated.

VI. Summary and Conclusion.

(1) The present study of inheritance of characters in linseed has established that the petal-colour in Indian types of linseed depends on the interaction of at least seven hereditary factors and this is in general in agreement with the investigations of Tammes based on European types of linseed. The main difference consists in the action of the intensification factor A which according to our evidence is either homozygous in all our types or is altogether absent in them. We have further evidence to postulate an additional factor N which reduces the intensity of colour in petals. So far we have no evidence to split up the factor B into B_1 and B_2 and it is also considered that D alone (in absence of B) can produce faint blue tinge in the petals, if E is present.

In the study of all other characters our theories differ materially from those put forward by Tammes.

(2) The crimped petals as noted in some of our types are produced by the interaction of three factors, namely C, D and E, which determine petal-colour. The crimped petals appear only when all these three factors are present. In absence of any one of them, the petal is non-crimped. A fourth factor B stops the formation of crimped petals even when C, D and E are all present. In all the genotypes with B the petal is always non-crimped, irrespective of the presence or absence of other factors. This differs materially from Tammes' theory.

(3) Our theory on the development of colour in seed is again very different from Tammes. On our evidence the inheritance of colour in seed-coat is dependent on four separate factors, namely, D, M, G and X, one of which (*i.e.*, D) determines flower-colour as well. M, in the presence of D, converts the fundamental yellow colour into fawn, and, if G is also present, fawn is changed into brown. If, however, D is absent, M has no action and the fundamental "yellow" colour is retained. This yellow changes to "grey" on addition of the factor G; this will, of course, become brown when D is added to it. The factor X acts only as an intensification factor converting yellow into dark yellow and fawn into dark fawn. Its action on grey and brown seed has not been noted.

(4) The inheritance of colour in anthers is determined by the factors B and D (which also determine petal-colour) in addition to another factor H (as suggested by Tammes) for which all our types are homozygous. In this case we entirely agree with Tammes.

(5) In the case of the style also all our types appear to be homozygous for the factor or factors which determine colour in this organ and hence in all our crosses the colour in style is determined by the presence or absence of some of the petal colour factors, *i.e.*, B, C, K, and E or F. Styles are blue only in those genotypes that possess these factors.

(6) The inheritance of colour in filaments is dependent on several mendelian factors in addition to some of the petal colour factors. Thus the colour in filament appears only when either of the duplicate factors Z_1 and Z_2 are present, and also the petal colour factors B, C, K and E or F. Apart from the duplicate factors Z_1 and Z_2, an inhibitory factor T determines the extent of colour in it. In the presence of this factor the colour produced by Z_1 and Z_2 is limited to the distal end of the filament as it occurs in Type 11.

In connection with the study of inheritance of colour in filaments, styles and stigma, it may be noted here that crosses Nos. 1 to 8 were made from an economic point of view and hence they do not necessarily include the types which may be most valuable for a complete genetic analysis of Indian linseed. We have, however, established that the development of colour in these organs is dependent on definite mendelian factors, which act in conjunction with some of the factors for petal colour and that in certain types the development of colour is further controlled by inhibitory factors.

(7) The colour in stigma is determined by a factor P which produces pink colour only when the factors B and C are present. If D is also present the stigma-colour is purple. An inhibitory factor "I", whenever present, turns purple or pink stigma into white.

(8) About 80 new hybrid linseeds have been isolated from these crosses and the most promising types are being tested for yield and oil-content.

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STUDIES IN INDIAN BARLEYS.

I. CLASSIFICATION OF TYPES ISOLATED AT PUSA.

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(With Plates IV-X and six text-figures.)

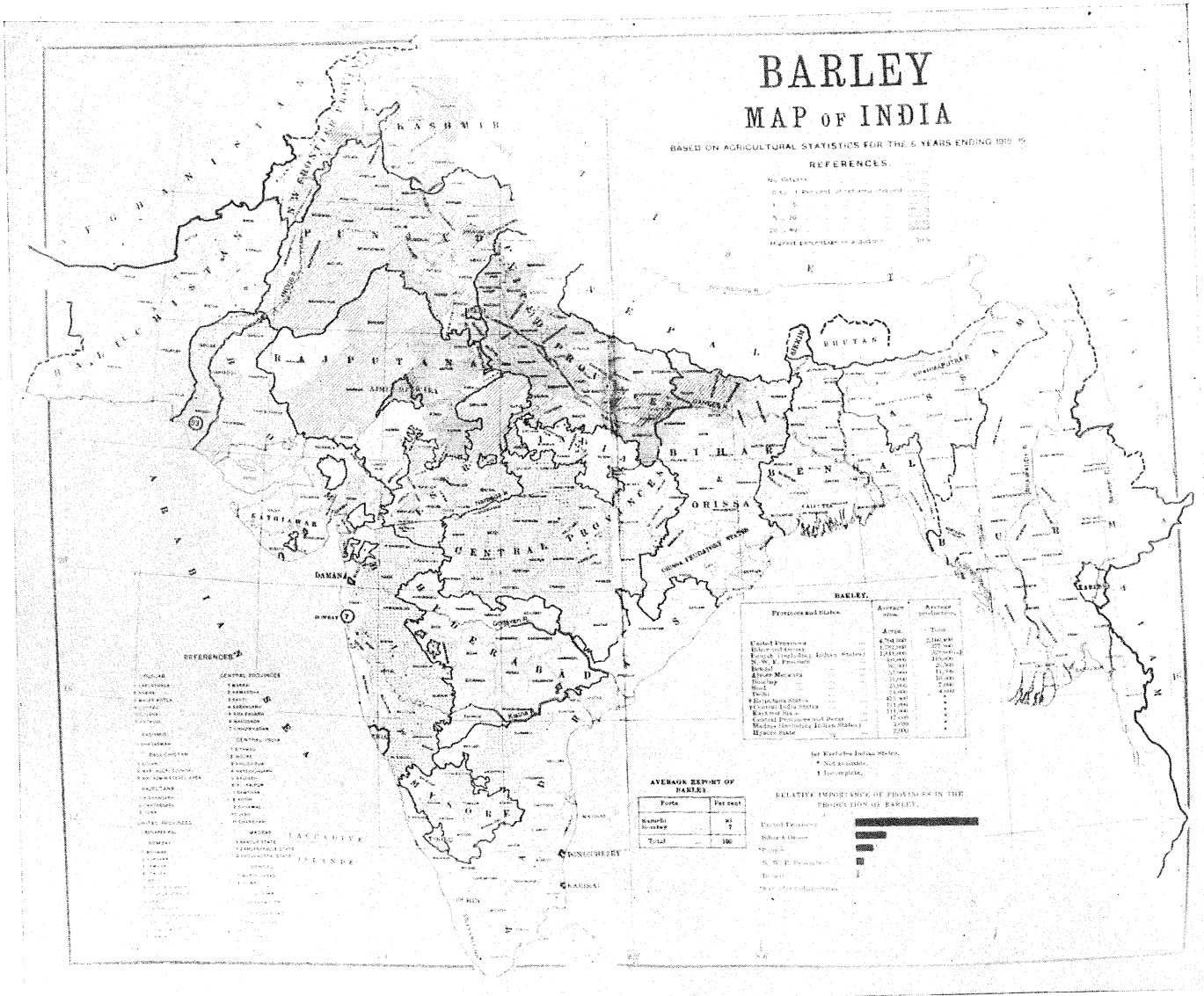
I. Introduction.

The average annual production of barley in the world during the period 1921 to 1925 was estimated at 173 million quarters of 400 lb. each. In this quantity Russia is the largest producer and is followed by the United States of America, while British India occupies the third place in the world's production [Duly, 1928] with an average of approximately 17 million quarters per annum.

Barley is one of the main staple crops of India and occupies about 6·8 per cent. of the cultivated area of this country. The total area under this crop generally ranges between 7 to 8 million acres. In 1928-29 the area under barley in each province was reported* to be as follows :—

* Supplement to the *Indian Trade Journal*, dated the 3rd April 1930.

PLATE IV.



[From the Crop Atlas for India.]

Province	Acres
Madras	2,974
Bombay	34,247
Bengal	81,700
United Provinces	4,434,736
Punjab	1,339,969
Burma	..
Bihar and Orissa	1,293,600
Central Provinces and Berar	17,479
Assam	..
North-West Frontier Province	232,408
Ajmer-Merwara and Manpur Pargana	61,652
Coorg	..
Delhi	33,930
TOTAL	7,532,695

This shows that the United Provinces [Rama Prasada, 1929] alone contribute 60 per cent. of the total produce of barley in India, and that these Provinces, together with the Punjab and Bihar and Orissa, constitute the main barley-growing tract in this country.

The Barley Map of India* (Plate IV) is based on Agricultural Statistics for the five years ending 1918-19, and furnishes a fair idea of the distribution of the crop.

The chief market for the surplus Indian barley is the United Kingdom, and in 1924 India contributed 23 per cent. of its imports of this crop. The total exports for the last 10 years are reported to be as follows :—

Exports of Barley from India.†

Year	Total	To British Empire
	Tons	Tons
1928-29	137,847	27,077
1927-28	71,628	33,613
1926-27	1,631	399
1925-26	42,396	20,461
1924-25	449,458	218,466
1923-24	168,704	97,502
1922-23	15,621	10,098
1921-22	9,878	347
1920-21	6,060	353
1919-20	1,656	182

* Barley Map of India taken from the *Crop Atlas for India*, published by the Commercial Intelligence Deptt., India, 1925.

† *Annual Statement of the Sea-borne Trade of British Empire and Foreign Countries*, Vol. I, 1919-20 to 1928-29.

Karachi (Plate IV) is said to be the main port for exporting barley and is responsible for about 93 per cent. of the total exports, while Bombay generally sends out the remaining 7 per cent.

Habitat. Barley occurs throughout the temperate and extra-tropical regions of the globe, and in India is met with from the plains to altitudes of 14,000 feet above the sea-level [Watt, 1908, 1].

History. Barley is amongst the most ancient of cultivated plants, but owing to the close resemblances between the different forms it cannot be said definitely which species are referred to in the early works on this crop. Dr. Bretschneider [Watt, 1908, 1] says that barley was one of the five cereals sown by the Emperor Shen-nung of China about 2700 B.C. According to DeCandolle [1904] the 2-rowed barley was cultivated by Semitic and Turanian peoples, while the 6-rowed barley was the most commonly cultivated in antiquity. Not only is it mentioned by Greek authors, but it has also been found in Egyptian monuments and in the remains of the lake-dwellings of Switzerland (age of stone), of Italy and of Savoy (age of bronze). Roxburgh [1874] believes that the 6-rowed form was the only kind of barley grown in India at the end of the last century. The very fact of its being used in many Hindu ceremonies, and the antiquity of the Sanskrit name *Yava*, indicates that the grain was known to the Aryans since very ancient times. The *Ain-i-Akbari* also shows that barley was considered to be one of the most important crops of Afghanistan and Kashmir during the reign of Akbar, and that a large part of the revenue of these countries was obtained from barley by exacting the usual two out of every ten *Kherwars* produced [Watt, 1908, 1].

Cultivation. Barley in India is a *rabi* crop, sown in October or November and reaped in March or April. It is either sown alone or sown mixed with wheat, gram, peas, lentils, linseed, rape and mustard, the mixed crop being the more usual. This crop is principally grown on soils which are light and sandy, and, as a rule, not highly manured. As barley does not require its seed-bed so finely pulverized as wheat, the number of ploughings before sowing is from two to six. The seed rate runs from about 60 to 120 lb. per acre. Irrigation is not required in some parts of India where the annual rainfall is quite sufficient, such as the Tirhut Division in Bihar and Orissa, and Meerut and Rohilkhand Divisions in the United Provinces of Agra and Oudh. Where necessary the crop is irrigated, but the irrigation is generally lighter than that for wheat and one or two waterings are held sufficient. Little weeding or topping is required and the total cost of growing an acre is estimated between Rs. 18 and Rs. 20. The average yield per acre ranges from 10 to 20 maunds. Better yields have been obtained in some improved types isolated at Pusa and described later in the course of this paper. The approximate market price generally is from Rs. 3 to Rs. 4 per maund (82 lb.).

Milling or Preparing. Watt [1908, 2] reports "The process of cleaning barley for food purposes is generally carried out by pounding in wooden mortars and winnowing, of by beating with a flat board. The grain is then ground into coarse

meal from which alone, or mixed with the meal of wheat or gram, *chapattis* are made and baked ; or a gruel or pasty mass is made, to which salt is added and the preparation eaten with garlic, onions or chillies. In either of these forms it is a staple article of food among the poorer classes. The grain, thus roughly cleaned and ground, is richer in albuminoids than the more carefully prepared culinary barley of Europe ; but at the same time it is more difficult to digest, and is thus partly unsuited for the dietary of dyspeptics or invalids.

In various parts of India barley is now largely employed in the preparation of beer or spirituous liquor, and the use of barley in Europe for malting and brewing is well known. Mollison gives an account of the qualities which give barley a special value for these purposes. It is also largely used as a horse and cattle fodder. In some parts of India the crop is cut two or three times when quite young without marked injury to the final yield of grain. The straw even of ripe barley makes a fairly good fodder when cut up as *bhusa*, but is inferior to that of wheat. The grain is a good feed both for horses and cattle, either given alone or mixed with gram."

Properties and uses. [Watt, 1908, 2] " The chemical composition of ordinary husked barley is given by Church as follows :—

Water	12·5 parts
Albuminoids	11·5 „
Starch	70·0 „
Fat	1·3 „
Fibre	2·6 „
Ash	2·1 „
	100·0

The nutrient ratio here is 1 : 6·3 and the nutrient value 84·5. In medicine, barley is a demulcent and easily digested, and is much used in the dietary of the sick. Malt extract has become extremely popular both as a nutritive and demulcent and as a means of rendering other medicines palatable."

Flowering. The barley plant, in common with the other cereals, has its inflorescence enclosed within a leaf which twists itself round the ear till the latter is mature and then gradually unfurls itself as the ear emerges out. It takes from six to eight days, from the time the tips of the awns are seen projecting out, to the time that the whole inflorescence is released completely from the sheath. The time taken for all the tillers of a plant to head out generally depends upon the variety, the vigour of the plant and the number of tillers per plant.

The complete flower in barley is composed of three anthers, an ovary with two brush-like stigmas and two thin bodies, the lodicules, situated on either side of the ovary. The flowers begin to open from the top of the ear and the opening generally

proceeds downwards, but no definite arrangement seems to exist. The following table shows the number of flowers that were observed to open per day in Type 12 in 1930 :—

Plant No.	No. of flowers opened on			
	1st day	2nd day	3rd day	4th day
1	9	9	18	10
2	8	5	23	7
3	5	4	27	10
Total .	22	18	68	27

It may be noted that the greatest number of flowers opened on the third day, and that the whole inflorescence completed its flowering in four days.

In most of the 6-rowed types the flowers begin to open when the ear is just above the flag leaf, but in the 2-rowed types, studied here, the opening of the flowers begin even while the ear is enclosed within the sheath. This ensures self-fertilization of almost cent. per cent.

Flowers generally begin to open on a normal bright day at about 9 A.M., and the flowering is over by 10-30 A.M. The filaments of the anthers elongate rapidly before the flowers begin to open and there is a slit formed between the lemma and the palea, the anthers dehisce and then hang out slightly. This, however, depends upon weather conditions. During cloudy or rainy weather the anthers have been observed to burst after emerging out, and this probably accounts for the bad setting which sometimes occurs if the weather continues to be bad for some days continuously. The slit formed is generally very small, due perhaps to the thinness of the lemma. The lemma and the palea remain separate only for 10 to 15 minutes when they again close up. In the 2-rowed barley the anthers burst out even before the slit is formed, while in Type 24 the slit has not been seen to form and the anthers burst and decompose within the flower itself.

Natural Cross-fertilization. Only one case of natural crossing has been observed in the Botanical Section so far. A natural cross between a 2-rowed and a 6-rowed variety was observed in 1929-30 and is under observation. Howard and others [1910] have observed that " A large number of pure line cultures of barley belonging to different varieties have been grown at Pusa, but no cases of natural crossing have so far been observed. Natural crossing, however, occurs sparingly in this crop as Rimpau [1891] found six cases in eight years."

Chromosome Numbers. The haploid chromosome number in barley is generally reported to be seven.

II. Isolation of pure types of barley.

The country crop as usual is generally a mixture of various unit species and can be improved by selection as regards yielding capacity, standing power, disease resistance and time of maturity. In order to obtain some improved strains a collection of samples from important barley-growing districts was made by the Botanical Section at Pusa about ten years ago and has since been added to considerably. From this collection 24 unit species have been isolated and some of these have proved very superior to the average mixed crop. The following table shows the locality from which the original seed of the selected types was obtained :—

TABLE I.

Type No.	Culture No.	Locality	Province
1	2-rowed-B	Selected from a stray plant in the Botanical Section, Pusa.	
2	2-rowed-C	Ditto.	
3	2-rowed-A	Ditto.	
4	2-rowed-D	Aligarh	United Provinces
5	Nepal-1	Nepal	Nepal State
6	10-10	Khurja	U. P.
7*	24-6	Ajmer	Rajputana
8	9-5	Hapur	U. P.
9	21-1	Cawnpur . . .	U. P.
10	Ben-4	Benares	U. P.
11	Ferozepore	Ferozepore. . . .	Punjab
12*	22-2	Arrah	Bihar and Orissa
13	17-2	Bareilly	U. P.
14*	20-7	Hardoi	U. P.
15	28-8	Larkana	Sind
16	19-2	Sitapur	U. P.
17	4-2	Ludhiana . . .	Punjab

* High-yielding types.

Type No.	Culture No.	Locality	Province
18	5-6	Saharanpur . . .	U. P.
19	18-3	Gola Gokaran Nath . .	U. P.
20*	23-10	Patna	Bihar and Orissa
21*	B-4	Local	Bihar and Orissa
22	16-8	Agra	U. P.
23	12-5	Kosi	U. P.
24	Ramdana	Darbhanga . . .	Bihar and Orissa
Strains rejected in 1930.			
	C-1	Local	Bihar and Orissa
	14-1	Kasganj	U. P.
	15-10	Hathras	U. P.
	1-10	Larkana	Sind
	S-1	Local	Bihar and Orissa
	S-2	Local	Bihar and Orissa

* High-yielding types.

III. Description and Scheme of Classification.

Duthie and Fuller [1882] describe the barley plant as follows :—

" An annual herb belonging to the tribe *Hordeae* of the natural order *Gramineae*. Stems many, quite smooth, 2-3 ft. high. Leaves few, the upper one close to the spike ; sheath smooth, striate ; ligule very short ; blade of leaf linear lanceolate rounded at the base, tapering gradually to the apex, glaucous green. Spikes linear oblong, compressed, 2-2½ in. long (without the awns) ; spikelets sessile, arranged in threes on two sides of a flattened rachis, lateral ones occasionally barren and rudimentary (var. *distichon*) ; glumes 2, small, setaceous, and awn-like, enclosing the three spikelets ; pales 2, lower one firm, 5-ribbed, rounded on the back and ending in a long stiff awn rough with forward prickles ; lower pale a little smaller than the upper, bifid, 2-veined, and with the margins inflexed. Lodicules 2, entire hairy. Stamens 3. exserted. Ovary hairy on the top. Stigmas 2, feathery. Fruit (the grain) usually with the pales adherent to it."

Barley belongs to the genus *Hordeum* in the natural order *Graminae*. Hackel divided this genus into three sub-genera and each sub-genus into species, all the cultivated barleys falling into one sub-species *sativum*. The genus *Hordeum* is distinguished among others of the grass family by the presence of one floret only in each spikelet. Wheat usually has three and oats two florets in each spikelet. The single-flowered spikelets are arranged in threes on alternate sides of the rachis. When all these are fertile, developing six vertical rows of grain the variety is known as a 6-rowed barley. If the lateral spikelets are sterile and only the middle row is fertile the variety is known as a 2-rowed type. In India the commonly cultivated form is the 6-rowed barley.

In his Memoir on barley, Wiggans [1921] has set out lucidly an account of the historical development of the classification of this crop. It will not be out of place, however, to give here a general survey of it.

Linnaeus [1748] the great founder of Systematic Botany divided the cultivated barley into *Hordeum hexastichon*, *H. vulgare*, *H. Zeocriton* and *H. distichon*. He took into consideration the three taxonomic characters of fertility, density and the adherence of the flowering paleae to the kernel for his classification. Following Linnaeus, Gustav Schubler separated *Distichon* into *Nutans* and *Erectum*, the separation being based upon the density of the panicle. Heuze [1872] working on a wider material expanded the classification and his study might be called the forerunner of the very good work of Kornicke [1885]. This German scientist believed that all the cultivated barleys belonged to *Hordeum vulgare*, L. and further divided this into four major groups as shown below :—

All spikelets fertile	*Hordeum polystichum* Doll.
All spikelets awned.	
Six-rowed barley, the spikes with 6 similar rows . . .	*H. Hexastichum*, L.
Four-rowed barley, two opposite rows formed by overlapping of 2 spikelets	*H. Tetrastichum* Kcke.
Only the middle spikelets awned. Middle barley . . .	*H. Intermedium* Kcke.
Only the middle spikelets fertile.	
Two-rowed barley	*H. Distichum*, L.

He divided these four primary groups into a number of species and described 103 sorts, the characters given the most weight being the adherence of the lemma and palea to the caryopsis, shape of outer glume, colour and shape of grain, shape of the spike, roughness or smoothness of grain and the character of the rachis. Kornicke's classification was for a long time considered the standard one. Voss [1885] using only the fertility of the lateral spikelets formed species and his varieties were separated from a consideration of the shape of spike, arrangement of rows of spikelets and their colour ; this was simpler but has not the merit of clearness.

Alterberg [1889] laid the foundation of the Swedish system of classification which was improved upon by Neergaard [1889] and perfected by Bolin [1893].

The distinction of varieties was based upon the fairly stable hairy character of the rachilla, lodicules and the lateral nerves of the glume.

The first English botanist who presented a comprehensive classification of barley was Beaven [1902]. He based his system mainly upon that of Kornicke but it is superior to that of the latter as he distinguished sub-species in the two-rowed varieties.

The German scientist Regel [1906-10] based his minor groups upon ecological factors and recognized only two densities and considered blue and purple as forms of white in the kernel colour.

In 1918 Harlan [1918] brought out his paper " The Identification of Varieties of Barley ". The chief merits of this work are clearness and plasticity of nomenclature. His key to the species is :—

Key to the Species.

All spikelets fertile (6-rowed barley).	
Lemmas of all florets awned or hooded	*vulgare*, L.
Lemmas of lateral florets bearing neither awns nor hoods . .	*intermedium*, Kcke.
Only the central spikelets fertile (2-rowed).	
Lateral spikelets consisting of outer glumes, lemma palet, rachilla and usually rudiments of the sexual organs	*distichon*, L.
Lateral spikelets reduced, usually to only the outer glumes and rachilla, rarely more than one flowering glume present, and never rudiments of sexual organs	*deficiens* Steud.

These four species of barley are divided into 32 varieties by Harlan who considers that these constitute the major variations in this crop. These varieties are further sub-divided into a number of sub-varieties. This system of classification advocated by Harlan may be considered ideal for barley.

The following table taken from Wiggans [1921] gives in a concise form the importance given to each main character by different workers :—

Summary Table showing the different use of characters by various investigators in the construction of their keys (after Wiggans).

Rank	Linnaeus 1748	Schubler 1818	Kornicke 1885	Voss 1885	Neergaard 1889 and Bolin 1893	Atterberg 1899	Beaven 1902	Carleton 1916	Harlan 1918	Wiggans 1921	Ranking adopted in this paper.
1	Fertility .	Fertility .	Fertility .	Fertility .	Fertility .	Terminal appendage.	Fertility . .	Fertility .	Fertility .	Fertility .	Fertility
2	Density .	Density .	Terminal appendage.	Shape of spike .	Shape of kernel.	Outer glumes .	Width of spike .	Colour of grain.	Adherence of lemma.	Adherence of lemma.	Adherence of lemma.
3	Adherence of lemma.	Adherence of lemma.	Number of rows or ranks.	Arrangement of spikelets.	Rachilla .	Adherence of lemma.	Length of internode.	Shape of spike.	Terminal appendage.	Terminal appendage.	Colour of kernel
4	..	..	Adherence of lemma.	Colour of spike .	Lateral nerves .	Colour of grain .	Adherence of lemma.	Terminal appendage.	Colour of kernel	Colour of kernel	Colour of leaf-sheath.
5	..	..	Outer glumes .	..	..	Fertility . .	Colour of grain .	Early habit of growth.	Outer glume .	Density .	Density
6	..	..	Colour of spike .	..	..	Length of internode.	Rough or smooth awns.	..	Colour of kernel	Rachilla .	Colour of foliage
7	..	..	Length of kernel	..	..	Width of spike .	Outer glumes .	..	Rough or smooth awns.	Rough or smooth awns.	Early habit
8	..	..	Length of spike.	..	..	Attitude of spike	Rachilla .	..	Density .	Early habit of growth.	Size of grain
9	..	..	Rough or smooth kernel.	..	..	Base of kernel .	..	..	Width of spike	Lateral nerves	..
10	..	..	Rachis .	..	..	Rachilla . .	..	..	Attitude of spike.	Shape of spike	..
11	..	..	..	..	..	Rough or smooth awns.	..	..	..	Colour of kernel	..

IV. Distinguishing Characters.

The barley plant, as a member of the grass family, naturally bears a strong resemblance to the other members of this group such as wheat and oats. Even at a very early stage of its development, however, barley can readily be distinguished by its habit of growth and the character of the ligule and auricles. These diagnostic characters are brought out in the following Table :—

TABLE II.

Character	Oats	Wheat	Barley
1. Early habit .	Erect or semi-erect .	Semi-erect . . .	Erect with leaves usually curled on themselves.
2. Ligule . .	Well developed and has a number of small teeth.	Developed, but more or less blunt.	Developed but blunt.
3. Auricles .	Absent . . .	Developed and hairy .	Well developed but glabrous.

Fig. 1 shows the differences that are found in the ligule and auricles in these three cereals.

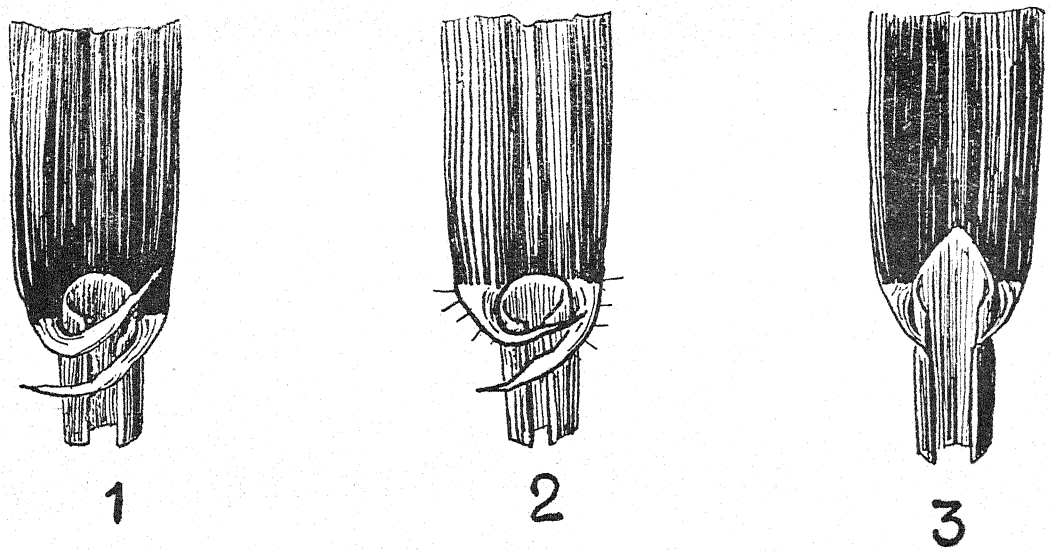


Fig. I. Showing the condition of ligule and auricles in the leaf of 1—Barley, 2—Wheat and 3—Oats.

The cultivated barley in India is generally the hulled 6-rowed form. Rarely the 6-rowed hulless form, such as the Pusa Ramdana variety (Type 24), is grown in some parts of India, but, as the average yield is rather less, it is never grown on a large scale ; 2-rowed barleys both hulled and hulless are grown to a very little extent.

Before a detailed classification of any crop can be attempted a thorough knowledge of its important characters must be made. In isolating the 24 types of barley from a large collection of material it was observed that these characters could be broadly divided into :—

(*a*) Morphological,
and
(*b*) Agricultural.

(*a*) Morphological Characters.

This group of characters is mostly confined to the morphology of the floral parts and they are more or less constant.

1. *Fertility.* As can be seen from the key to the species mentioned before there are four degrees of fertility, two in the 6-rowed and two in the 2-rowed forms. These are based upon the nature of the lateral spikelets, the central spikelet being always fertile in all cases. In the 6-rowed barley the lateral as well as the central spikelets are all fertile and may be either awned or hooded or may even be without any appendages. In the 2-rowed barley the lateral spikelets generally contain all the glumes, paleæ and lodicules but the sexual parts are either sterile or abortive. In the *deficiens* group of the 2-rowed barley the laterals contain rudimentary sexual parts or are so reduced as to present only the outer glumes. Because of the stability of these characters and their easy recognition, they have been used by all writers as taxonomic characters of the first magnitude.

2. *Characters of the hull.* After fertility the character of the hull assumes importance and forms a very wide basis for classification. The flowering glume and the paleæ in most varieties fuse with the kernel forming what are called the hulled barleys. The hulless or the ' naked ' barleys, on the other hand, husk out easily and in that condition resemble grains of wheat, excepting that the position of the embryo is parallel with the length of the grain instead of being at right angles with it as in wheat.

3. *Terminal appendages of the lemma.* Awns on the lemma of the central as well as the lateral spikelets are invariably present in all the 6-rowed barleys grown at Pusa. These represent the generally cultivated types grown all over India. In the 2-rowed forms only the central spikelet has mostly a rounded tip or occasionally an awn, while the lateral florets have mostly a rounded tip or occasionally a small point. The hooded Nepal barley described by many authors has not yet been

included in the present collection, but attempts are being made to procure this. The awn in this form is replaced by a trifurcate appendage of three lobes which are supposed to be a partial duplication of the three florets at a node of the rachis ; these florets often bear fertile stamens and rarely set seed. The awns of all the 24 types of barley, so far isolated, are rough with small barbs, which are closer to one another in some types than in others. It is reported that in a few potentially valuable agronomic forms, such as the Black Barbless of the Michigan Farm [Down, Brown and Clark, 1929], the awns are smooth, rendering the handling of the grain at harvest and threshing time easy.

4. *Colour of the spikelet.* Different grades of colour have been recognized by different workers in the kernels and glumes of barley, and the weight given to them varies. It must be pointed out that, though the major groups of colour stand out prominently, the intermediate grades are very much influenced by weather conditions at ripening and harvest. Many investigators have divided their colour groups into white, black, yellow, violet, purple, and blue-grey. The standards created by Harlan, however, are the most clear. The colour in the hulled varieties is based upon the pigments located in the lemma and such of those in the aleurone layer as may show through the lemma. The first division consists of those without colour resulting in either a white or yellow grain. Then come the blue and purple colours —the former due to the colourless glume and blue aleurone layer and the latter being determinable by the purple colour of the glume and paleæ. The colours recognized in the Pusa types are—white, white with a purple tinge, yellow light and deep, purple and bluish-grey (Plate VI). The black barleys where the colour is in the glumes are not found in India. The colour is more readily detected in the hulless varieties and the same grades of colour as in the hulled forms are present in these. Some workers have used the colour of the spike as a character for classification, but it is likely to be more difficult than making out the colour in the spikelet, and so this has not been attempted here. At Pusa Type 21 has shown some changes in the development of colour in the spike from the green to the ripe stage. In the early stages the ear has a greenish colour which develops into purplish and on maturing assumes more or less a buff colour. This is shown in Plate VII.

5. *Leaf-sheath colour.* The leaf-sheath at the first internode discloses variations in colour in the different types. There is a purple wash as well as lines on the internode grading to lighter shades in some types and grading almost to *nil* in others. The influence of light has a good deal to do in all colour characters in plants, and it is probable that a deep purple coloured sheath in barley might later change into a dull colour and *vice versâ*, depending on the intensity of light it receives, but it may be assumed that the colour can neither be completely inhibited nor developed anew. This character does not seem to have been utilized by previous investigators as a group characteristic or as a varietal difference. In this paper, however, the colour of the leaf-sheath has been considered to differentiate the types into two broad divisions—those with purple-coloured sheaths and those with green ones.

6. *Density.* Density is taken to mean the number of spikelets per unit length of rachis, generally 10 cm. This is a character in barley to which varying degrees of importance are given by different workers. In fact, it was given equal weight with fertility in the grouping of sub-species by earlier authors; later it was used only as a varietal difference. The original idea that density was a result of fertility is disproved by the fact that lax and dense forms occur together in the 2-rowed as well as in the 6-rowed barleys. A good deal of variation in this character occurs in the several types. The real difficulty is to set limits between the dense, lax and intermediate forms. An empirical division based upon the measurements of barley ears, as suggested by Archer [1922], has been adopted in the present studies. The length of 10 internodes, or the length between one notch and the sixth from it, was measured with a pair of dividers and scale on one side of the ear. Denoting this length by the letter L the density in millimetres is given by $\frac{1000}{L}$. Care was taken to measure the distance always from a particular notch, the third from the bottom being always taken in these studies. Types with a density above 31 were classed as *dense*, those from 27 to 31 as *medium* and those with a density below 27 were considered *lax*. It may be pointed out, however, that this character is not without limitations as season and time of sowing specially have a decided effect upon it—a good season and an early sowing generally lessening the density by producing a longer ear-head.

A direct consequence of density is the shape given to the ear. A long spike with a lax habit has a tendency to nod while a short dense ear is invariably stiff and erect. Again, the angle of inclination of the lateral spikelets to the rachis is dependent upon the density of the ear. The longer the distance between the internodes in the lax ear-heads, the smaller the angle of inclination of the laterals as there is more room for the development in a vertical direction. Harlan [1918] has used this character for differentiating the sub-varieties. When the inclination is small, making the awns more or less parallel to the rachis, the sub-variety is called *Parallelum*, but if the awns emerge at a greater angle forming a pyramidal structure the sub-variety is classified as *Pyramidatum*. The angle of inclination is rather a difficult thing to measure, but the following method was used for the present study. The sixth spikelet from the bottom was taken in every case and all the other spikelets were removed; the inner edge of the rachis was made to coincide with a vertical and the point of attachment with a particular division on a squared paper. The tangent was then determined and from this the angle was arrived at by a reference to a Table of Trigonometrical Ratios. In the present classification this angle was used to denote the nature of the ears. Those types which had an angle between 36° and 40° were classed as *broad-eared*, those between 30° and 35° as *medium-eared* and those below 30° as *narrow-eared* types.

7. *Outer glumes.* The outer glumes do not show any variations in the types studied. In all the Pusa types, except Type 1, the outer glumes are narrow, thin

and slightly hairy, and have a small appendage which is generally smooth. Some investigators elsewhere have found a slight variation in the width of the outer glumes, which in some cases has been reported to be expanded and to be almost ovate in shape. This expansion is limited only to the central spikelet.

8. *Rachilla.* Unlike the other grasses, the rachilla in barley is attached to the base of the floret and is prolonged beyond the base forming a distinguishing character of the genus. Some workers such as Archer [1922] reported the existence of certain variations in the size and hairiness of the rachilla—some were long and bristly, others short and hairy, while there were some with the intermediate condition as well. Such differences, however, were not met with in the types studied at Pusa. Here the rachilla of the central spikelet in all the 24 types isolated was long with few hairs, while that of the lateral spikelets of the 2-rowed varieties was very long, almost filamentous and possessed very few bristles.

(*b*) Agricultural Characters.

The characters described above are well developed specific differences which can more or less safely be relied on as definite and constant features under all conditions existing in different parts. But when considering a comparison between varieties, it is necessary none the less to give full weight to variations existing in these as a result of varying conditions of soil and climate under which they are grown. Responses shown by varieties to differences of environment are different. These characters called ' gross ' or ' mass ' characters are given below and serve as a guide to the differences of the ultimate units or strains.

1. *Root-system.* Very little attention has hitherto been given to this character in schemes of classification advocated for barley. Although this character has not been used for any clear cut differentiations between the various types isolated at Pusa, a study of the root-systems of almost all the types has been made. Four kinds of root-systems have been observed [Bose and Dixit, 1931] and they have been classed as—

(1) Mesophytic—where the shallow roots are well developed and given off at right angles to the tillers, while the deep roots are comparatively poor. This is further sub-divided into two groups according to the working depth of the root-system—

(i) Mesophytic—A—has a working depth of 80 to 90 cm. Example, Type 21.

(ii) Mesophytic—B—has a working depth of 50 to 60 cm. Example, Types 1 and 2.

PLATE V.

Type 21 standing well in the field (Left) and Type 20 Badly lodged (Right).

(2) Semi-Mesophytic—where the shallow roots are poorer than in (1) and though the deep set of roots is poor it is better than in the above, both in number and branching. Example, Type 13.

(3) Semi-Xerophytic—where the shallow roots are well developed but are given off obliquely downwards, and the deep root-system has longer and greater number of roots than in (1) and (2). Example, Type 22.

(4) Xerophytic—where the shallow root-system is poorly developed, while the deep root-system is generally well formed and deeply penetrating. Example, Type 15.

Shallow-rooted types with roots spreading at right angles to the tillers belong to Bihar and to localities with abundant soil-moisture, while deep-rooted types with poorly developed shallow root-systems have originated from seed brought from drier tracts of the United Provinces, Sind and Rajputana. Under Pusa conditions, where the average annual rainfall is estimated to be 47 inches, the shallow-rooted types are all earlier in maturity and are amongst the highest yielders, while the deep-rooted types are generally late and do not fare well. In their early habit the shallow-rooted types are erect or semi-erect, while the deep-rooted types have a tendency to be bushy and spreading in their early stages of growth. There is no definite relation between the height of the plants and the depth of the roots in the different types.

2. *Early habit.* The habit in the early stages of growth in a plant's life is an important character in many cold countries, and there this character is taken to separate spring from winter varieties. Varieties which are erect at all stages and have only a few leaves are called spring varieties; those which are bushy in their early stages can withstand frost and are suited for winter are known as winter types. Differences have been observed in this character in the Pusa types and are clearly recognized in the early stages. Later on as the plants grow all the types assume a more or less erect habit.

3. *Tillering.* It is a matter of common observation that a character like this changes a good deal with season and soil; it is only when varieties are grown under conditions which preclude chances of differentiation that a comparison can be made. Though in practice an ideally uniform soil never exists, an idea of inherent capacity for tillering can be got by growing the varieties on a fairly uniform soil for a period of five or six years.

4. *Lodging.* Varieties with a weak straw often lodge badly, especially on heavy ground. Lodging usually occurs late in the period of growth of the barley and at a rather vital time, bringing about heavy losses both in the quality and quantity of the crop. Stiffness of straw is of very great importance in a barley type. The yield of a lodged field is greatly reduced, and such a crop is difficult to harvest. Type 21 outstands all Pusa types in the stiffness of straw. It is this character which makes it stand well even under undesirable conditions, while some other types, like Type 20, lodge badly under the very same conditions. Plate V shows Type 21 on the left

standing well, while Type 20 has lodged badly on the right. A study of the transverse sections of the stem of some types revealed some differences. Figures 2 and 3 show these sections in Types 21 and 20.

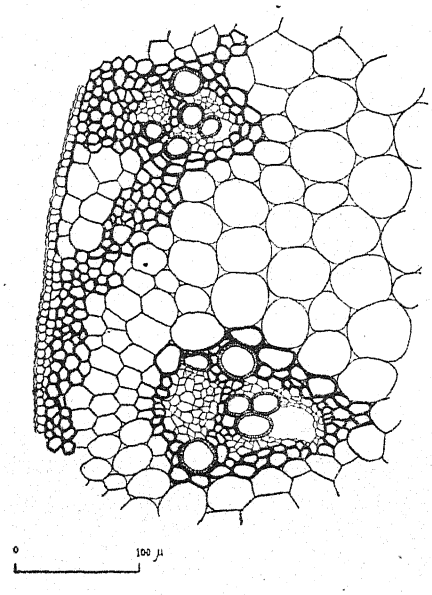


Fig 2.

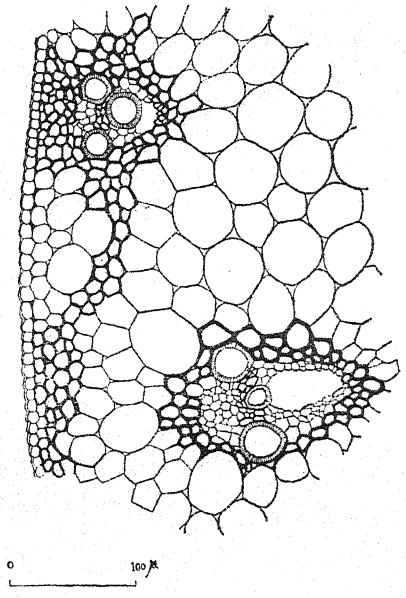


Fig 3.

Showing transverse sections of the stem of Type 21—Non-lodging (Fig. 2) and Type 20—Lodging (Fig. 3).

In Figure 2 (Type 21—Non-lodging) the mechanical tissue towards the periphery is much more developed than in Fig. 3 (Type 20—Lodging). These figures represent only a small portion of the transverse section of the stems. The occurrence of this increased amount of sclerenchymatous tissue all round the stem naturally increases the rigidity of the stem of a non-lodging type.

5. *Foliage.* The colour of vegetation is susceptible to a good deal of variation and is very easily influenced by conditions of growth. But under a set of uniform conditions of environment there are clean cut differences in the types studied with regard to this character. There are types with dark green leaves with a bluish tinge. These are described in the following pages as *bluish green* as contrasted with the light coloured ones termed *light green.* The intermediate condition denominated *green* in the description of types is a little more difficult to diagnose ; personal factor operates a good degree in the right classification of this character (Plate VIII). The length and breadth of leaves are again variable but there is not such a wide difference as to make them a basis for varietal recognition.

6. *Height.* This again is a character which varies within very wide ranges and is influenced by the climate and growth factors. The extremes are anyhow clearly made out and hence this character may be used, if necessary, for a description of the different types. In the descriptions that follow, types which have an average height below 85 cm. are classed as *short,* those ranging between 86 and 95 cm. as *medium,* while those that are above 95 cm. are termed *tall.*

7. *Size of grain.* It will probably appear a little strange to class size of grain as a mass character rather than a morphological one. But by way of explanation it may be noted that the size of the grain of cereals, like some other vegetative characters, is subject to variation by the conditions under which they are grown. Here again the extremes are easily made out by an examination of the aggregate. One fact, however, must be borne in mind that whereas the size of grain in a two-rowed pure type of barley is more or less uniform, it can never be so in a 6-rowed barley. In the latter there invariably is $\frac{1}{3}$ well formed grain arising from the central spikelet and $\frac{2}{3}$ a little smaller in size, those developing from the lateral spikelets.

8. *Maturity* is generally measured by the number of days taken from seeding to heading. This is one of the most important characters of a crop and is one which is likely to vary within great limits when a variety changes its habitat. It is a well-known fact that the duration of a crop depends to a great degree on the time of sowing. Exotic barleys from Europe and America sown under Pusa conditions flower very late in the season and for this reason most of them dry up before they can set any seed. In most parts of Northern India barley is generally sown at the end of October or the beginning of November and the number of days taken from that date till the appearance of the ear-head is taken as an index of maturity rather than the actual date of ripening, because ripening is materially influenced by weather conditions. Hot dry weather will hasten, while cool, damp weather will retard the date of ripening. In the present study, types which took 61 to 72 days to head out were termed *early ;* those in which the emergence took place from 73 to 84 were called *medium* and those which took more than 85 days were classed as *late.*

9. *Bushel weights.* The weight per bushel is one of the main criterion of the commercial quality of many crops. In barley, however, the appearance and condition of the sample are of much greater importance, and a barley of a lighter natural

weight may be better for malting purposes than a heavier one. Bushel weights of the important barley types isolated here were recorded for the last six years and are given below :—

Table III.

Statement showing average bushel weights of Pusa barleys during 1925-1930.

Type	Bushel weights in lb.						Average weight in lb.
	1925	1926	1927	1928	1929	1930	
2	..	..	..	..	47·0	47·5	47·25
6	52·0	56·6	45·0	45·2	38·5	41·0	45·40
7	51·0	47·4	44·0	44·0	44·2	44·2	45·8
8	49·5	44·3	46·0	44·5	41·1	38·1	43·9
9	52·0	48·6	46·3	46·0	41·8	43·3	46·3
11	..	..	..	..	43·0	39·9	42·5
12	51·5	52·0	46·9	46·9	44·2	42·9	47·5
13	53·0	50·4	48·7	47·5	42·2	46·2	47·3
14	52·0	50·6	45·8	47·0	45·9	44·6	47·7
15	47·5	44·5	47·5	41·5	35·0	34·8	41·8
16	52·5	51·2	50·0	49·8	46·0	47·1	49·4
17	56·0	51·2	48·2	48·7	41·6	46·9	48·6
18	51·0	45·3	41·7	42·2	37·2	42·8	43·3
19	50·5	48·2	45·2	45·0	43·4	44·4	46·2
20	51·0	46·7	45·5	45·7	46·3	44·0	46·5
21	50·5	47·6	43·0	45·5	43·4	42·2	45·4
22	54·0	51·5	51·0	48·0	41·2	..	49·1
23	52·0	50·2	46·7	46·2	43·6	46·4	52·5
24	66·0	67·2	64·3	63·0	62·9	61·7	64·2

It may be pointed out that the weight per bushel does not give any idea about the yielding capacity of any of the above types and does not seem to bear any relation with the same. Type 21 (old B-4) for instance, which is the highest yielder, has an average bushel weight of 45·4 lb., while type 17, which is a very poor yielder

under Pusa conditions, has an average bushel weight of 48·6 lb. in the last six years recorded above. Type 24, which is hulless and thrashes out like wheat, has the highest weight of 64·2 lb. to the bushel although it is an indifferent yielding type.

10. *Nitrogen content.* The nitrogen content of the barley grain is the surest guide to malting quality. The following analyses from the 1930 crop were made by the Imperial Agricultural Chemist, Imperial Institute of Agricultural Research, Pusa, to whom my thanks are due for this.

TABLE IV.

Showing the percentage of organic nitrogen on dry basis in Pusa barleys, 1930.

Description of samples Barley Type.	Percentage organic nitrogen on dry basis.
1	2·44
2	2·68
3	2·73
4	2·54
5	2·40
6	1·89
7	1·75
8	1·85
9	1·91
10	2·07
11	1·87
12	1·71
13	1·74
14	1·93
15	2·04
16	1·83
17	1·87
18	2·00
19	1·85
20	1·97
21	1·92
22	1·89
23	1·85
24	2·14

11. *Diseases.* Butler [1918] reports the occurrence of the following fungus diseases in barley :—

(i) Covered Smut (*Ustilago Hordei*, (Pers.) Kell. and Sw.). "Scattered cases of this disease occur in the barley fields all over Northern India, but never to the same extent as oat smut."

(ii) Loose Smut (*Ustilago nuda* (Jens.) Kell. and Sw.). "This is much rarer than the last in India, which is fortunate as it is more difficult to control."

(iii) Rust (Dwarf Rust) (*Puccinia simplex* (Koern.) Eriks. and Henn.), Black rust (*Puccinia graminis*, Pers.), Yellow Rust (*Puccinia glumarum*, Eriks., and Henn.). "Barley like wheat, is subject to the attacks of three distinct rusts, two of which are the same as two of the wheat rusts, while the dwarf rust of barley takes the place of orange rust of wheat."

(iv) Stripe Disease.—A good deal of damage is done to some types of barley at Pusa by *Helminthosporium sativum*, Pk. and B. A record of this has been maintained by the Imperial Mycologist, Pusa, to whom my thanks are due for supplying me the following detail for the 1930 crop in the Botanical Section.

TABLE V.

Showing barley Helminthosporium observations in Botanical Area, Pusa, during 1929-30.

Type	Nature of *Helminthosporium* attack on						
	3rd Dec. 1929	22nd Dec. 1929	6th Jan. 1930	21st Jan. 1930	5th Feb. 1930	20th Feb. 1930	5th Mar. 1930
2	S	S	S	S	S	S	S
6	S	S	F	F	B	B	B
7*	S	S	S	F	F	F	B
8	S	F	F	F	F	F	F
9	S	S	F	F	F	F	B
11	S	S	F	F	F	F	F
12*	S	S	S	F	F	F	F
13	S	S	S	S	F	B	B
14*	S	S	S	S	S	S	S
15	S	F	F	F	F	F	F
16	S	S	F	F	F	F	F
17	S	S	S	S	S	S	S

*High-yielding types.

Type	NATURE OF *Helminthosporium* ATTACK ON						
	3rd Dec. 1929	22nd Dec. 1929	6th Jan. 1930	21st Jan. 1930	5th Feb. 1930	20th Feb. 1930	5th Mar. 1930
18 . . .	S	S	S	S	S	F	F
19 . . .	S	S	F	F	F	F	F
20* . . .	S	S	S	S	S	S	S
21* . . .	VS	VS	VS	VS	S	S	S
22 . . .	VS	S	S	S	S	F	F
23 . . .	S	S	S	S	F	F	F
24 . . .	VS	VS	VS	VS	VS	S	S

*High yielding types.

VS= Very slight attack. F= Fair attack.

S=Slight attack. B= Bad attack.

It is interesting to note that Type 21 is the best barley for North Indian conditions and it is this which seems to be attacked the least by this disease. The other high-yielding forms marked (*) also are types with more or less slight attack. This is an example which shows that disease-resistance is an important criterion in the selection of suitable types of a crop for a particular locality.

The intermittent hot water treatment described below is sometimes advocated as a measure of control for the stripe disease. In order to observe the efficacy of this treatment an experiment was conducted in 1928-29. One-tenth acre plots of Types 14, 20 and 21 respectively were sown with treated seed and a similar area with ordinary dry seed as control. The hot water treatment consisted of putting the seeds in cloth bags and placing them in water at about 104° F. for two hours, and then in water at 118° F. for 10 minutes, then dipped again for about a minute in a bath at 104° F. and left for two hours in a warm room. Equal weights of seed were sown in each plot and the final yields obtained were :—

Type	YIELD IN LB. IN	
	Control plot	Treated plot
21	344	426
20	266	283
14	252	256

This shows that the yields in all treated plots were higher than those in the corresponding controls and appreciably so in Type 21 where the incidence of *Helminthosporium* was markedly less in the treated plot.

V. Key to Types.

	Type
I. Two-rowed barley. *Hordeum distichon*, L.	
Grains Hulled.	
Seed light yellow.	
Leaf sheath green, foliage light green	1
Seed white.	
Leaf sheath purple, foliage green	2
Grains Hulless.	
Seed light yellow.	
Leaf sheath purple, foliage green	3
Seed purple.	
Leaf sheath purple, foliage green	4
Seed deep purple.	
Leaf sheath purple, foliage green	5
II. Six-rowed barley. *Hordeum vulgare*, L. variety *Pallidum*.	
Grains Hulled.	
Seed deep yellow.	
Leaf sheath green.	
Ears medium dense, foliage green	6
Ears lax, foliage green	7
Ears lax, foliage bluish green	8
Seed light yellow.	
Leaf sheath green.	
Ears dense, foliage green	9
Ears lax, foliage light green.	
Early habit erect	10
Early habit spreading	11
Ears lax, foliage bluish green	12
Leaf sheath purple.	
Ears medium dense, foliage green	13
Ears medium, lax foliage bluish green.	
Early in maturity	14
Late in maturity	15
Seed white.	
Leaf sheath green.	
Ears dense, foliage green	16
Leaf sheath purple.	
Ears medium dense, foliage light green.	
Grains small and thin	17
Grains bold and plump	18
Foliage green	19
Ears lax, foliage green	20

Seed white with a purplish tinge.
Leaf sheath green.
Ears medium dense, foliage bluish green.
Early in maturity 21
Medium in maturity 22
Ears lax, foliage green 23
Grains Hulless. *H. vulgare*, var. *cœleste*.
Seed (husked) bluish grey.
Leaf sheath green.
Ears dense, foliage bluish green 24

VI. Description Types

I. 2-ROWED BARLEYS. (PLATE IX.)

Type 1. Early habit erect; root-system mesophytic B, poor; leaf-sheath colour green; foliage light green, short and narrow leaves; tillering poor; height 57 cm., short; density 32·1; ear short, dense, outer glumes broad and awned; kernel hulled; short and plump, light yellow; weight of 1,000 grains 45·0 gm., bushel weight 48 lb., maturity early (65 days).

This is the only type with the outer glumes broad and awned.

Type 2. Early habit spreading; root-system mesophytic B, poor; leaf-sheath colour purple; foliage green, short and narrow leaves; tillering poor; height short (70 cm.); density 40·3; ear short, dense, and does not come out well from the sheath, outer glumes narrow and pointed; kernel hulled, roundish and very plump, white; weight of 1,000 grains 35·3 gm.; bushel weight 47 lb.; maturity late (107 days).

Type 3. Early habit spreading and bushy; root-system mesophytic B, poor; leaf-sheath colour purple; foliage green; tillering moderate; height short (71 cm.); density 32·5; ear short, dense; kernel hulless, round and plump, light yellow; weight of 1,000 grains 29·0 gm., bushel weight 50 lb.; maturity late (92 days).

Type 4. Early habit bushy; root-system xerophytic; leaf-sheath colour purple; foliage green; tillering moderate; height short (61 cm.); density 33·0; ear short and dense; kernel hulless, short and plump, purple; weight of 1,000 grains 26·5 gm., bushel weight 50 lb.; maturity late (105 days).

Type 5. Early habit erect; root-system mesophytic B; leaf-sheath colour purple; foliage green; tillering good; height medium (88 cm.); density 33·2; ear very long and dense; kernel hulless, round and plump, purple; weight of 1,000 grains 35·0 gms., bushel weight 50 lb.; maturity late (89 days).

Glumes and awns purple, fading to lighter shades on ripening.

II. 6-ROWED BARLEYS. (PLATE X.)

Type 6. Early habit erect; root-system semi-mesophytic; leaf-sheath colour green; foliage green; tillering moderate; height short (76 cm.); density 30·3; ear medium in length and breadth, outer glumes narrow and pointed; kernel hulled, thin and medium, deep yellow; weight of 1,000 grains 33·9 gm., bushel weight 45·4 lb.; maturity medium (74 days).

Type 7. Early habit erect ; root-system semi-xerophytic, vigorous ; leaf-sheath colour green ; foliage green ; tillering good ; height short (77 cm.) ; density 27·0 ; ear long, narrow and lax ; kernel hulled, long and plump, deep yellow, weight of 1,000 grains 42·2 gm., bushel weight 46 lb. ; maturity early (69 days).

Type 8. Early habit semi-erect ; root-system semi-mesophytic ; leaf-sheath colour green ; foliage bluish-green ; tillering moderate ; height short (81 cm.) ; density 22·2 ; ear medium, long, narrow and lax ; kernel hulled, medium in size, deep yellow, weight of 1,000 grains 37·4 gm., bushel weight 44 lb. ; maturity medium (75 days).

Type 9. Early habit erect ; root-system semi-mesophytic ; leaf-sheath colour green ; foliage green ; tillering moderate ; height short (83 cm.) ; density 33·0 ; ear short, medium broad and dense ; kernel hulled, medium in size, light yellow, weight of 1,000 grains 27·6 gm., bushel weight 46 lb. ; maturity medium (77 days).

Type 10. Early habit erect ; root-system semi-mesophytic ; leaf-sheath colour green ; foliage light green, long and broad leaves ; tillering moderate ; height medium (88 cm.) ; density 23·5 ; ear long, narrow and lax ; kernel hulled, long and plump, light yellow ; weight of 1,000 grains 28 gm., bushel weight 39 lb. ; maturity early (70 days).

Type 11. Early habit spreading ; root-system xerophytic ; leaf-sheath colour green ; foliage light green, short and narrow leaves ; tillering moderate ; height tall (104 cm.) ; density 24·2 ; ear long and medium broad, lax ; kernel hulled, long and thin, light yellow, weight of 1,000 grains 24 gm., bushel weight 43 lb. ; maturity late (94 days).

Type 12. Early habit erect ; root-system mesophytic ; leaf-sheath colour green; foliage bluish green, long and broad leaves ; tillering good ; height medium (86 cm.); density 23·2 ; ear medium length and breadth, lax ; kernel hulled, long and rather plump, light yellow, weight of 1,000 grains 38 gm., bushel weight 48 lb. ; maturity early (71 days) ; a high-yielding type.

Type 13. Early habit spreading ; root-system semi-mesophytic ; leaf-sheath colour purple ; foliage green ; tillering poor ; height medium (91 cm.) ; density 29·4; ear medium in length and breadth, rather dense ; kernel hulled, long and thin, light yellow, weight of 1,000 grains 29·3 gm., bushel weight 47 lb. ; maturity medium (79 days).

Type 14. Early habit erect ; root-system mesophytic ; leaf-sheath colour purple ; foliage bluish green ; tillering moderate ; height short (79 cm.) ; density 24·8 ; ear medium, narrow and lax ; kernel hulled, long and rather thin, light yellow, weight of 1,000 grains 34·7 gm., bushel weight 48 lb., maturity early (61 days).

Type 15. Early habit spreading ; root-system xerophytic ; leaf-sheath colour purple ; foliage bluish green ; tillering moderate ; height tall (103 cm.) ; density 23·3 ; ear medium narrow and lax ; kernel hulled, long, narrow and thin, light yellow, weight of 1,000 grains 27·9 gm., bushel weight 42 lb. ; maturity late (100 days).

Type 16. Early habit semi-erect; root-system semi-xerophytic; leaf-sheath colour green; foliage green; tillering poor; height medium (91 cm.); density 29·2; ear medium in length and breadth, rather dense; kernel hulled, medium in size, white, weight of 1,000 grains 31·8 gm., bushel weight 49 lb.; maturity medium (84 days).

Type 17. Early habit spreading; root-system xerophytic; leaf-sheath colour purple; foliage light green; tillering moderate; height medium (93 cm.); density 30·3; ear medium in length and breadth, rather dense; kernel hulled, short, narrow and thin, white, weight of 1,000 grains 22·4 gm., bushel weight 49 lb.; maturity medium (81 days).

Type 18. Early habit spreading; root-system xerophytic; leaf-sheath colour purple; foliage light green; tillering moderate; height medium (86 cm.); density 30·3; ear long, narrow and rather dense; kernel hulled, long, plump, white, weight of 1,000 grains 27·3 gm., bushel weight 43 lb.; maturity medium (83 days).

Type 19. Early habit spreading; root system semi-xerophytic, vigorous; leaf-sheath colour purple; foliage green; tillering good; height medium (85 cm.); density 30·6; ear medium long, narrow and rather dense; kernel hulled, medium in size, white, weight of 1,000 grains 27·4 gm., bushel weight 46 lb.; maturity medium (85 days).

Type 20. Early habit erect; root-system mesophytic; leaf-sheath colour purple; foliage green, leaves long and broad; tillering good; height tall (99 cm.); density 22·5; ear long, narrow and lax; kernel hulled, long and plump, white, weight of 1,000 grains 40·3 gm., bushel weight 47 lb.; maturity early (72 days); a high-yielding type with very long ears.

Type 21. Early habit semi-erect; root-system mesophytic, vigorous; leaf-sheath colour green; foliage bluish green, leaves long and broad; tillering good; height short (83 cm.); density 30·2; ear medium long, broad and rather dense; kernel hulled, long and plump, white with a purplish tinge, weight of 1,000 grains 38·1 gm., bushel weight 45 lb.; maturity early (72 days). This is the best yielder under North Indian conditions. Glume and awns purple fading to lighter shades on ripening. (Previously called B-4.)

Type 22. Early habit semi-erect; root-system semi-xerophytic; leaf-sheath colour green; foliage bluish green; tillering poor; height medium (89 cm.); density 29·3; ear long, narrow and rather dense; kernel hulled, small and plump, white with a purplish tinge, weight of 1,000 grains 34·8 gm., bushel weight 49 lb.; maturity medium (79 days); sheds badly on over ripening.

Type 23. Early habit erect; root-system xerophytic; leaf sheath colour green; foliage green; tillering moderate; height short (80 cm.); density 25·7; ear long, narrow and lax; kernel hulled, long and plump, white with a purplish tinge, weight of 1,000 grains 41·0 gm., bushel weight 53 lb.; maturity medium (79 days).

Type 24. Early habit semi-erect; root-system mesophytic; leaf-sheath colour green; foliage bluish green, leaves short; tillering moderate; height medium (92

cm.) ; density 41·2 ; ear very short, broad and compact ; kernel hulless, short and plump, bluish grey, weight of 1,000 grains 25·1 gm., bushel weight 64·2 lb. ; maturity early (62 days) ; previously known as Ramdana.

VII. Economic Aspects.

The object of every economic plant-breeder is to produce a variety which will bring an increased monetary return to the cultivator. This increased profit may be obtained by an improvement in the yield per acre and to a less extent by the quality of the grain. To the grower it is absolutely immaterial whether the increased yield of the new variety is due to potential yielding power, to enhanced disease-resistance or to a better adaptability of the root-system. If the amount of increased profits that accrue by taking up an improved variety *is* brought home to the cultivator, he is not as slow to take it up, as is sometimes thought.

Yield. An increased amount of produce per acre is therefore the main criterion in the selection of a crop. For a number of years comparative trials with all the important selections were made at the Botanical Section and the more promising types selected for final trial. In 1928-29 a yield trial was conducted with Types 21, 20 and 12 (B-4, B-23 and B-20) respectively against a mixed local strain. The results obtained may be gauged from the following table [Shaw and Bose, 1929] :—

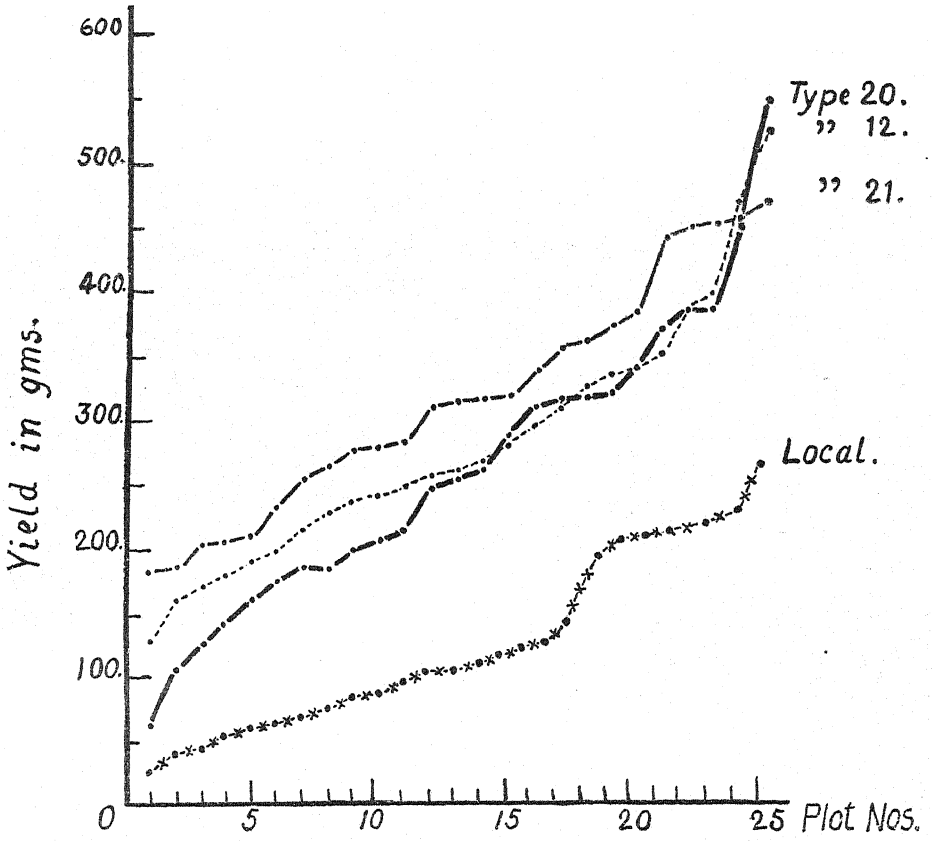
TABLE VI.

Mean yields and other statistical constants for the four types of barley in Series I, II, III and IV, in 1928-29.

Series	Variety	Size of plot	No. of plots	Mean gm.	Standard deviations	Probable errors of the mean
I	A (B-4) .	3′×3′	25	314·72	89·19	12·03
	B (B-23) .	3′×3′	25	260·68	113·35	15·29
	C (Local) .	3′×3′	25	124·52	69·93	9·43
	D (B-20) .	3′×3′	25	276·52	94·01	12·68
II	A (B-4) .	3′×3′	50	417·44	128·39	12·25
	B (B-23) .	3′×3′	50	363·82	108·58	10·36
	C (Local) .	3′×3′	50	186·86	81·12	7·74
	D (B-20) .	3′×3′	50	349·96	116·14	11·08
III	A (B-4) .	25′×2′	6	1,464·167	417·509	114·98
	B (B-23) .	25′×2′	6	1,301·166	322·26	88·75
	C (Local) .	25′×2′	6	557·5	141·24	38·90
	D (B-20) .	25′×2′	6	1,292·167	374·11	103·03
IV	A (B-4) .	25′×3′	6	2,738·5	602·38	165·89
	B (B-23) .	25′×3′	6	2,170·333	302·9	83·42
	C (Local) .	25′×3′	6	1,633·0	602·64	165·94
	D (B-20) .	25′×3′	6	2,092·5	223·67	61·60

This clearly shows the superiority of the three Pusa types over the local strain and that Type 21 (B-4) is the best yielder under all the four series. The graph given below will also give an idea of the comparative yields of these four different

barleys as was obtained in Series I of the experiment reported above. Yields of plots, each 3 feet square, are arranged for each type, in order of their magnitude and do not of course mean that the yields increased systematically from plot to plot



YIELD PER PLOT IN BARLEY YIELD TRIALS
1928-29.

Fig. 4.

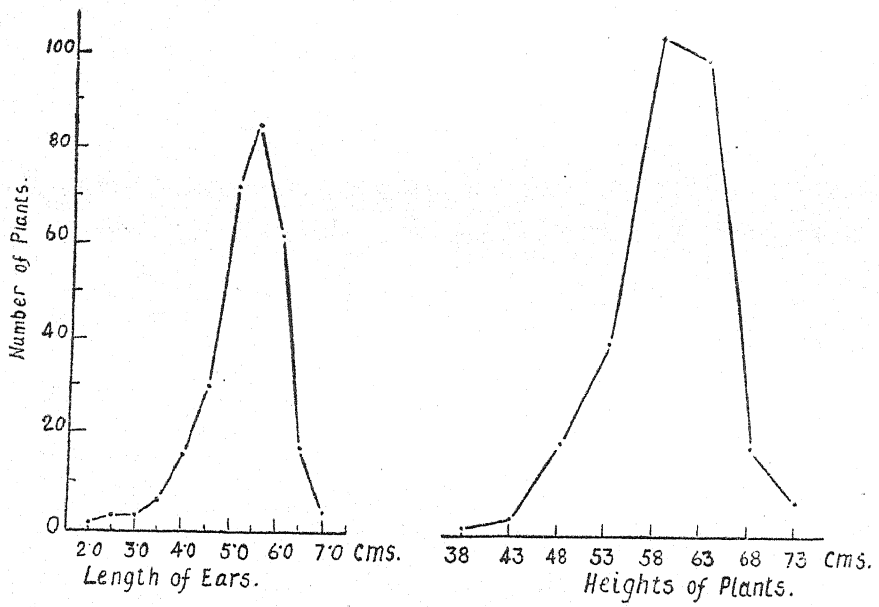
In 1929-30 Type 21 produced an outturn of 2,570 lb. to the acre in the Botanical Section, Pusa. Seed of some types was distributed in 1929 and very favourable reports have been received regarding them. The Deputy Director of Agriculture, Shahjahanpur, U. P., reports the following outturns on areas of one acre :—

	lb. per acre.
*B-4 (Type 21)	2,755
B-22 (Type 12)	2,807
B-23 (Type 20)	2,651

* Types, 21, 12 and 20 were called B-4, B-22 and B-23 respectively in the *Annual Reports of the Imperial Economic Botanist, Pusa,* and in the *Agricultural Journal of India,* XXIV. 1929, 371-396.

The Dholi Concern in the Muzaffarpur District, Bihar and Orissa, has obtained an yield of 3,845 lb. to the acre with Type 21 from an area of 0·25 acre, while the Model Farm at Beawar (Rajputana) has also secured an outturn of 2,152 lb. to the acre with the same type. The Benipur Concern in Bihar has reported a yield of 2,214 lb. (or 27 maunds) to the acre on an area of 8·5 acres. As described already, barley is generally sown in India mixed with gram, peas, lentils, etc., and the average outturn of mixed barley seed generally ranges from 12 to 15 maunds (984 to 1,230 lb.) to the acre and very rarely it goes up to 20 maunds (1,640 lb.). The increased outturn of Pusa barleys and especially of Type 21 will be of great value to the ryot. Extensive trials with some of these promising types are desirable, and some work on the malting capacity of some of these selections would be of great value.

The following graphs show the frequency distributions of the length of ears and the height of plants in Type 21 as observed in 1928. The curves approximate normal frequency curves and thus establish the purity of the type.



FREQUENCY DISTRIBUTION SHOWING THE LENGTH OF EARS AND THE HEIGHT OF PLANTS IN TYPE 21 BARLEY IN 1928.

Fig. 5.

Straw.—In India, barley straw is fed to the cattle to a great extent. When cut up as *bhusa* it makes good fodder although it is somewhat inferior to wheat straw.

The ratio of grain weight to straw weight was determined in some types in 1928 and is shown below :—

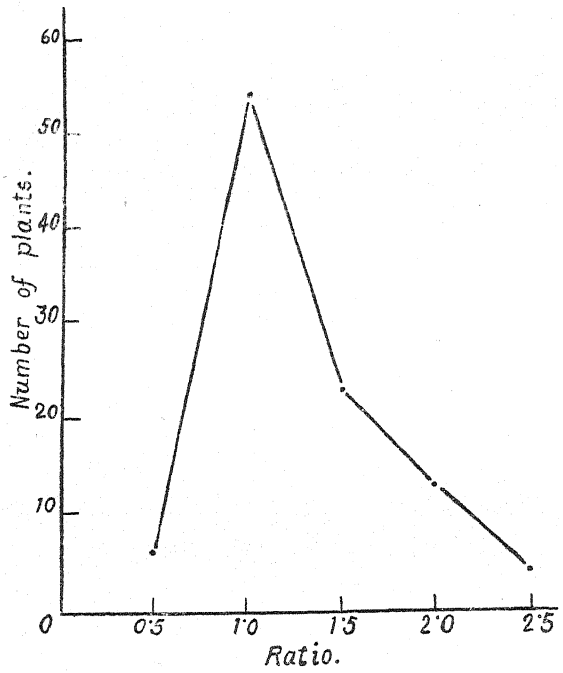
TABLE VII.

Showing the ratio of grain weight to straw weight obtained in a yield trial with some types in 1928. (Arranged according to the magnitude of their yield of grain.)

Type	Yields in chataks from plots 800 sq. feet in area		Ratio of Grain : Straw
	Grain	Straw	
21	321	422	1 : 1·31
14	316	395	1 : 1·25
9	310	524	1 : 1·69
7	284	423	1 : 1·49
12	275	422	1 : 1·53
20	273	415	1 : 1·52
13	259	409	1 : 1·58
16	255	481	1 : 1·88
8	250	372	1 : 1·49
22	235	371	1 : 1·58
23	213	384	1 : 1·80
6	194	309	1 : 1·59
17	147	422	1 : 2·87
19	140	299	1 : 2·14
18	119	191	1 : 2·45
24	97	421	1 : 4·34
15	78	352	1 : 4·51

It is apparent from the above table that the ratio of the grain weight to straw weight generally depends on the type itself and that in the high-yielding types the straw weight is approximately $1\frac{1}{2}$ times the grain weight. In types which do not

grow well in this locality (Types 15 and 24) the straw weight is proportionately much higher. This ratio was also determined in 100 plants of Type 21, selected at random from a field of this type, and the graph shown below gives a clear view of the results obtained.

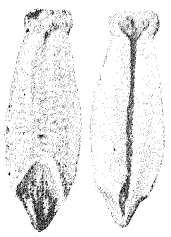


FREQUENCY DISTRIBUTION SHOWING THE RATIO OF GRAIN TO STRAW - WEIGHTS IN TYPE 21 BARLEY IN 1928.

Fig. 6.

In conclusion, I wish to express my thanks to Dr. F. J. F. Shaw, the Imperial Economic Botanist, Pusa, at whose instigation the work was undertaken, for his constant advice and criticism during the course of the investigation ; also to Messrs. P. D. Dixit, and M. B. V. Narsinga Rao, post-graduate students in the Botanical Section, Pusa, for considerable help rendered during the last two years of the work.

2-Rowed Barleys.



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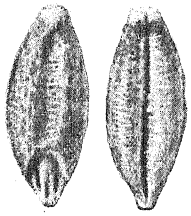

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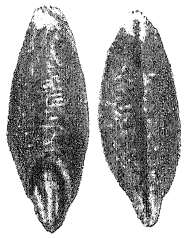

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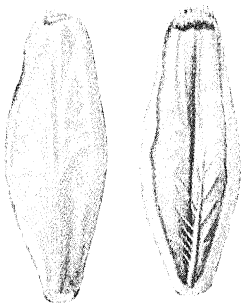

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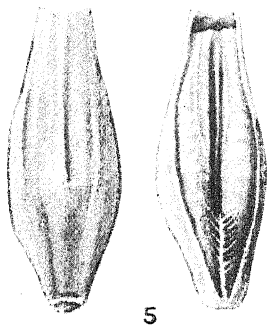

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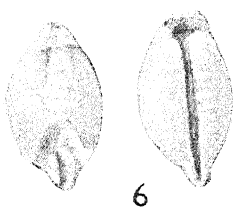
6-Rowed Barleys.



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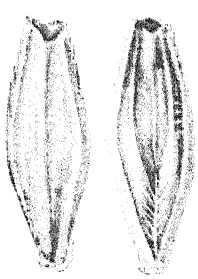

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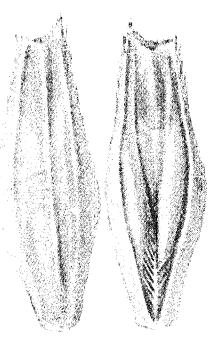

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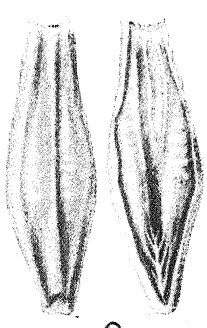

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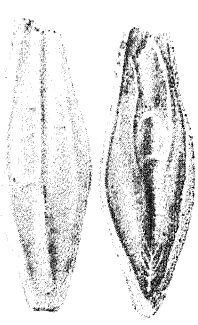

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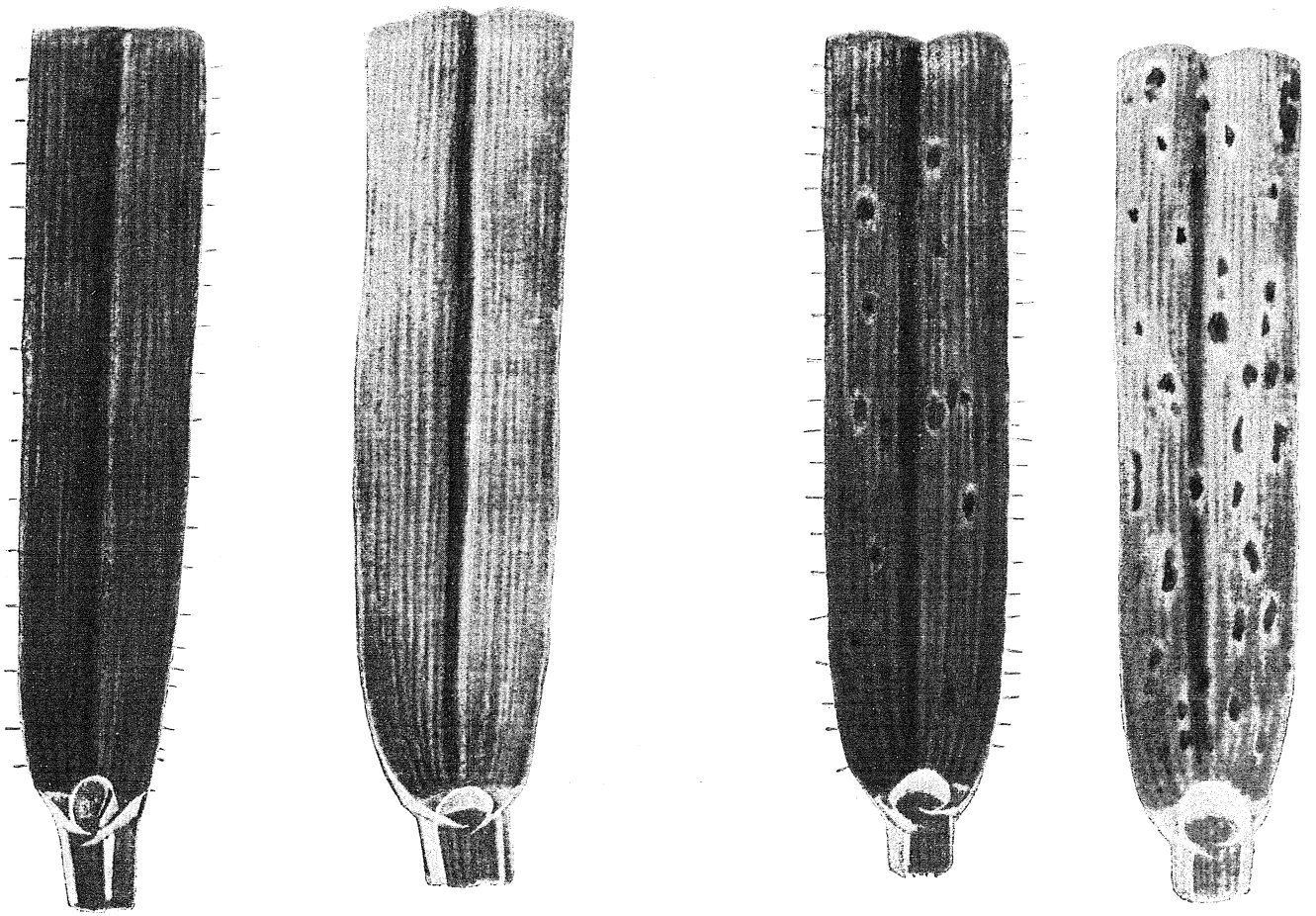
THE COLOUR OF THE BARLEY KERNEL.

1 to 3, 2-rowed hulless—Types 3, 4 and 5 respectively;
4 and 5, 2-rowed hulled—Types 2 and 1;
6, 6-rowed hulless—Type 24;
7 to 10, 6-rowed hulled—Types 17, 12, 6 and 21 respectively.

DEVELOPMENT OF COLOUR IN THE EAR OF TYPE 21.

1, 1a, and 1b—Colour in the early stages of growth in the ear, stem and spikelet; 2 and 3—Colour in the intermediate stages; 4, 4a, and 4b—Colour in the mature stage in the ear, stem and spikelet.

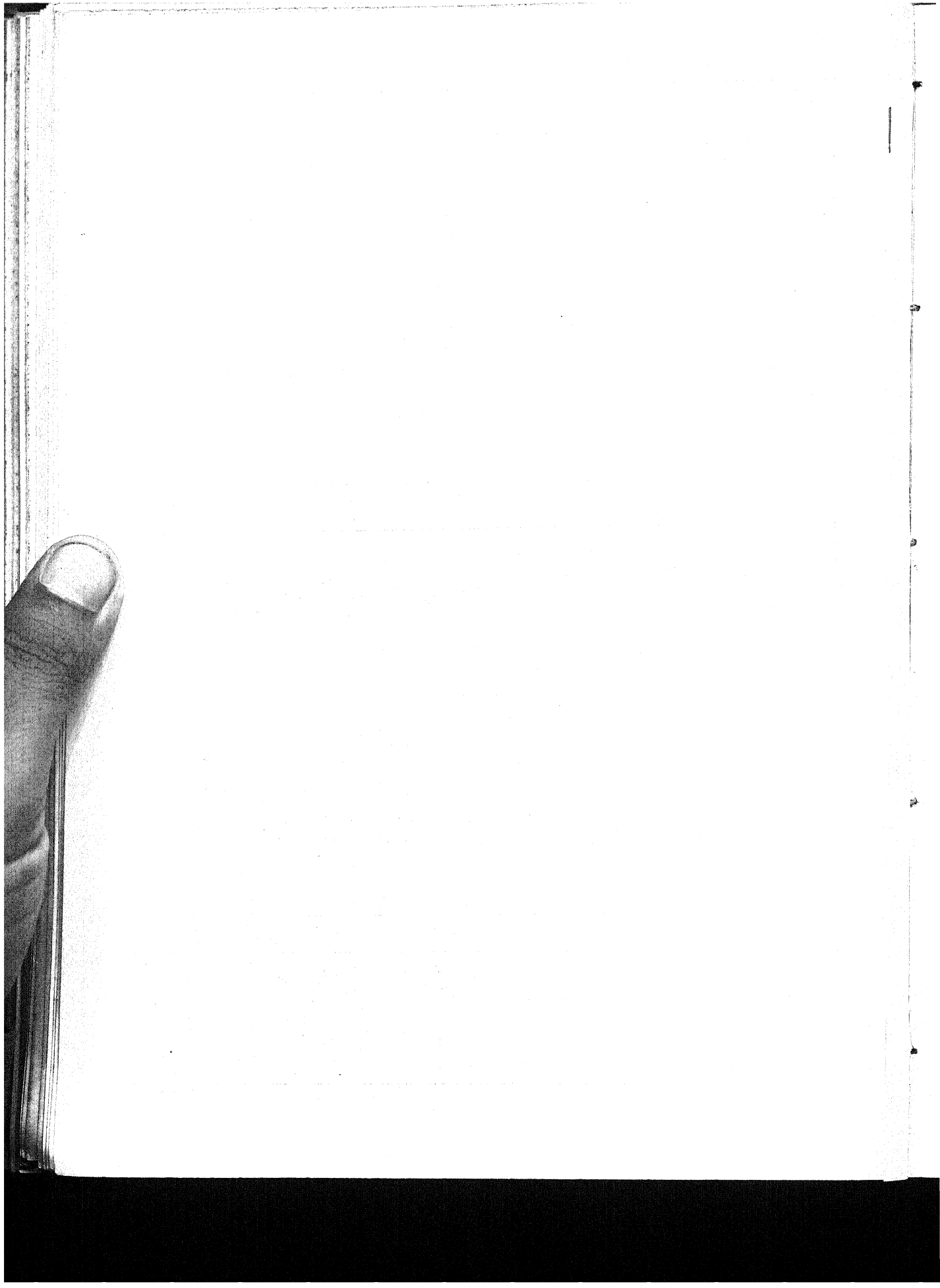


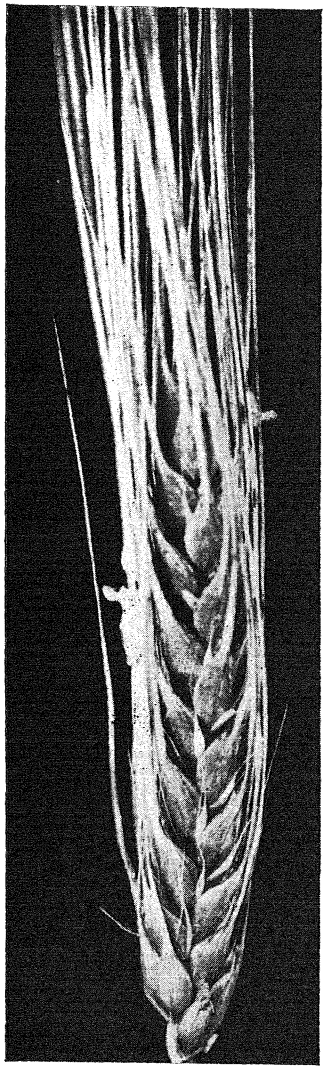
Colour of Leaves in Type 21 (Bluish green—Fig. 1) and Type 6 (Green—Fig. 2) and also the nature of *Helminthosporium* attack in these two types Figs. 1a and 2b).

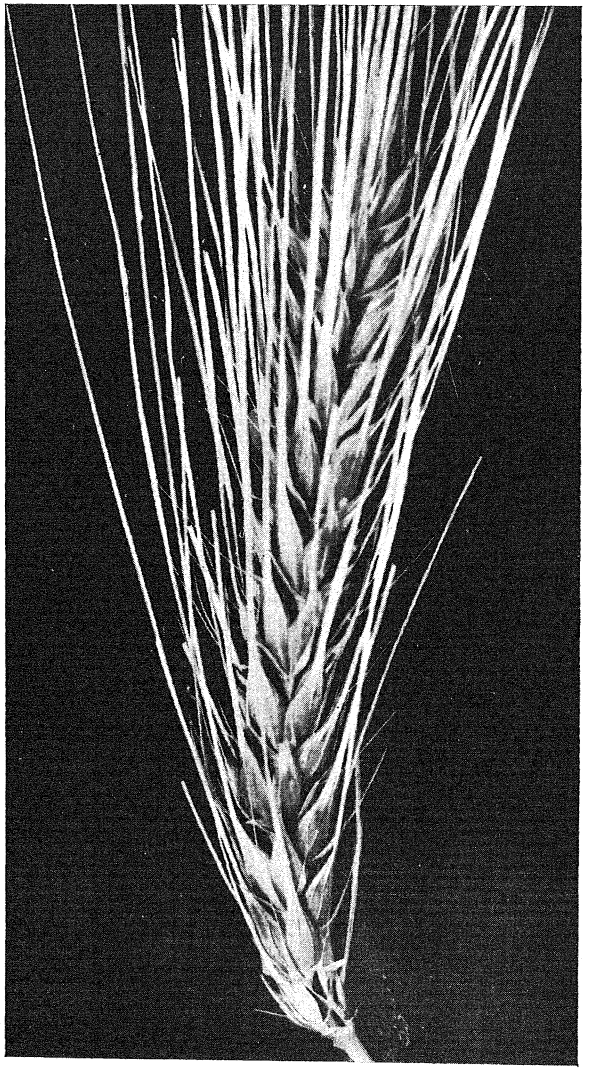
PLATE VIII

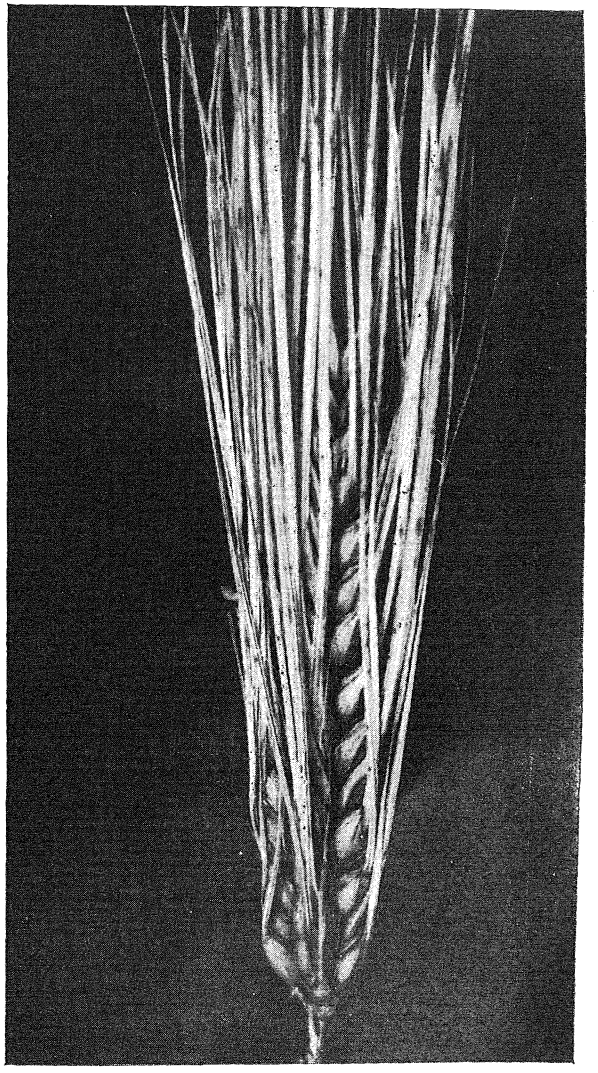
Ears in 2-rowed Barley. Types 1, 2 and 4 (from the right).

PLATE IX.



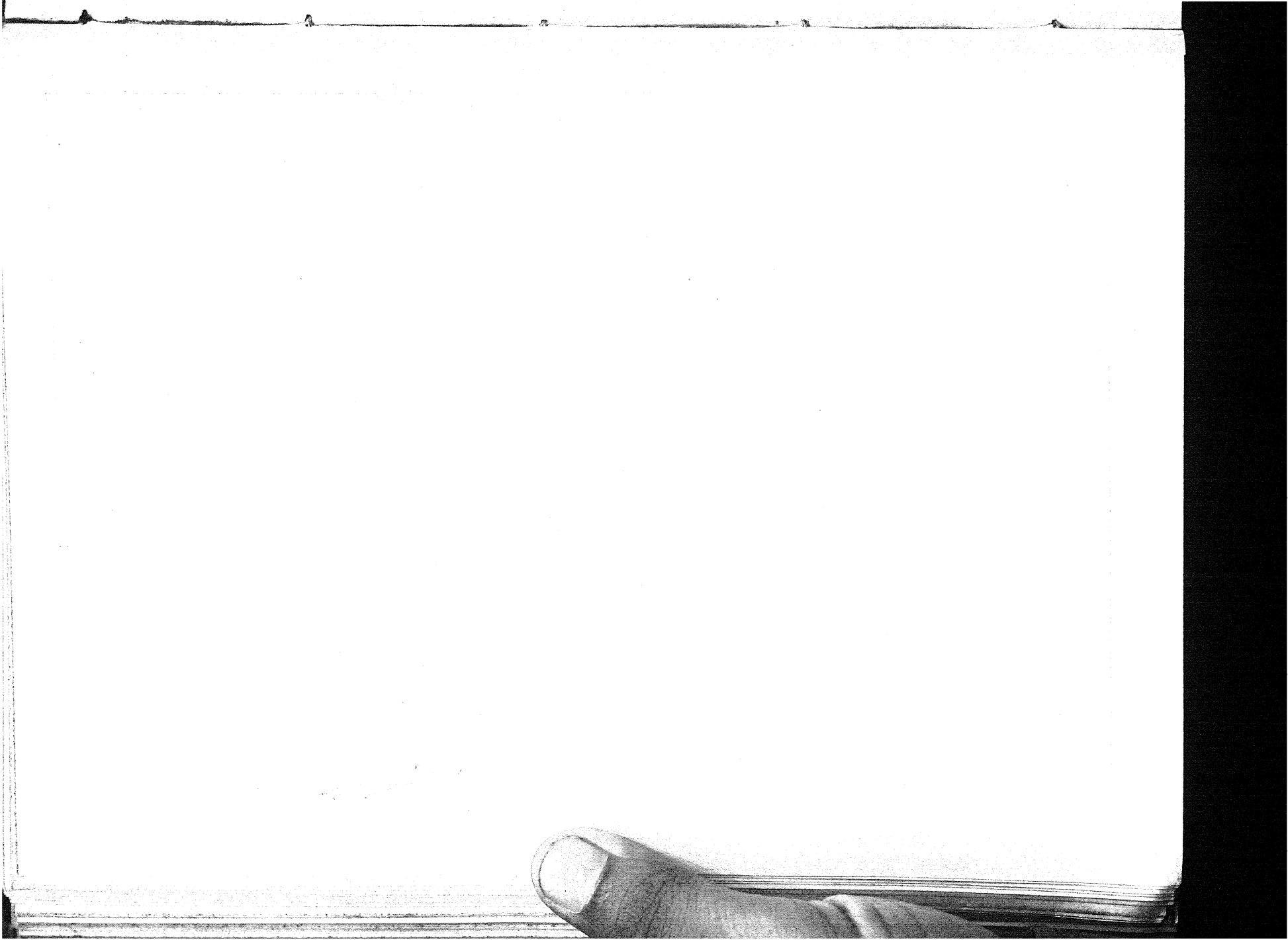






Ears in 6-rowed Barley. Types 24, 20 and 21 (from the right).

PLATE X.



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STUDIES IN INDIAN BARLEYS.

II. THE ROOT-SYSTEM.

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(With Plates XI-XIII and one text figure.)

I. Introduction.

Notwithstanding the enormous number of field and variety trials carried out annually all over the world, very little attention is paid to the study of the root systems of agricultural crops. The importance of this part of a plant cannot be

over-emphasized. " The roots are the means by which the soil and plant are brought into gear," [Howard, 1924] and as such deserve great attention. A thorough knowledge of root habits and root activities is essential for many problems connected with the selection of types for distribution to various localities. A certain type may prove itself to be a very good yielder as the result of variety trials at one station, but it may fail to give similar results in another place, because its root-system is not adapted to the soil conditions in the second locality. For example, " Wheat Pusa 6, which suits Bihar best, does not do well in the drier wheat-growing areas of the Indo-Gangetic plain, while Pusa 12, which was apt to be disappointing on the heavier lands of Pusa, when tried in the United Provinces quickly came into favour, the reason being that the former is shallow-rooted while the latter is deep-rooted—which is a distinct advantage in open and drier alluvial soils of the United Provinces." [Howard and Howard, 1917.]

Twenty-four types of barley have been isolated in the Botanical Section at Pusa from a collection of samples obtained from the important barley-growing districts of India. [Bose, 1931.] This involved the inclusion of material from widely different soil and agricultural conditions. It was considered advisable, therefore, to carry out a comparative study of the root-system of the various types, so as to find out whether any relation existed between the nature of the root-system in a type and the locality from which the type was collected. The time of maturity, habit, height and yield were also considered in relation to the root habit in the various types.

Studies of root-systems in crops are also useful in obtaining the maximum benefit from the application of fertilizers, irrigation, methods of tillage, inter-culture and rotation.

II. Methods.

The root-systems of 24 types of barley were studied in 1929, and in 1930 the types were re-examined and six new types were also studied. At the time of examination the plants were mature and ready for harvest. The types were sown in beds $4' \times 12'$, each type separated from the other by a line of gram. A passage about four feet broad was left between adjoining beds. The examination of roots was easy as the plots were kept free from weeds, and the root-system could therefore be traced with accuracy and certainty. Sometimes the roots of the separating gram line caused some difficulty, but they could be distinguished by their thickness and whiter colour from the thinner and somewhat more brownish roots of barley.

Four types of barley, two growing on opposite sides of the passage, could be studied at a time, so that the excavation of only one trench was enough to study four types together. By doing so not only much labour was saved but comparisons were made easy and points of contrast between the types made more obvious. The trenches with more or less vertical walls were excavated in the passage, taking care that they were at least six to eight inches away from the

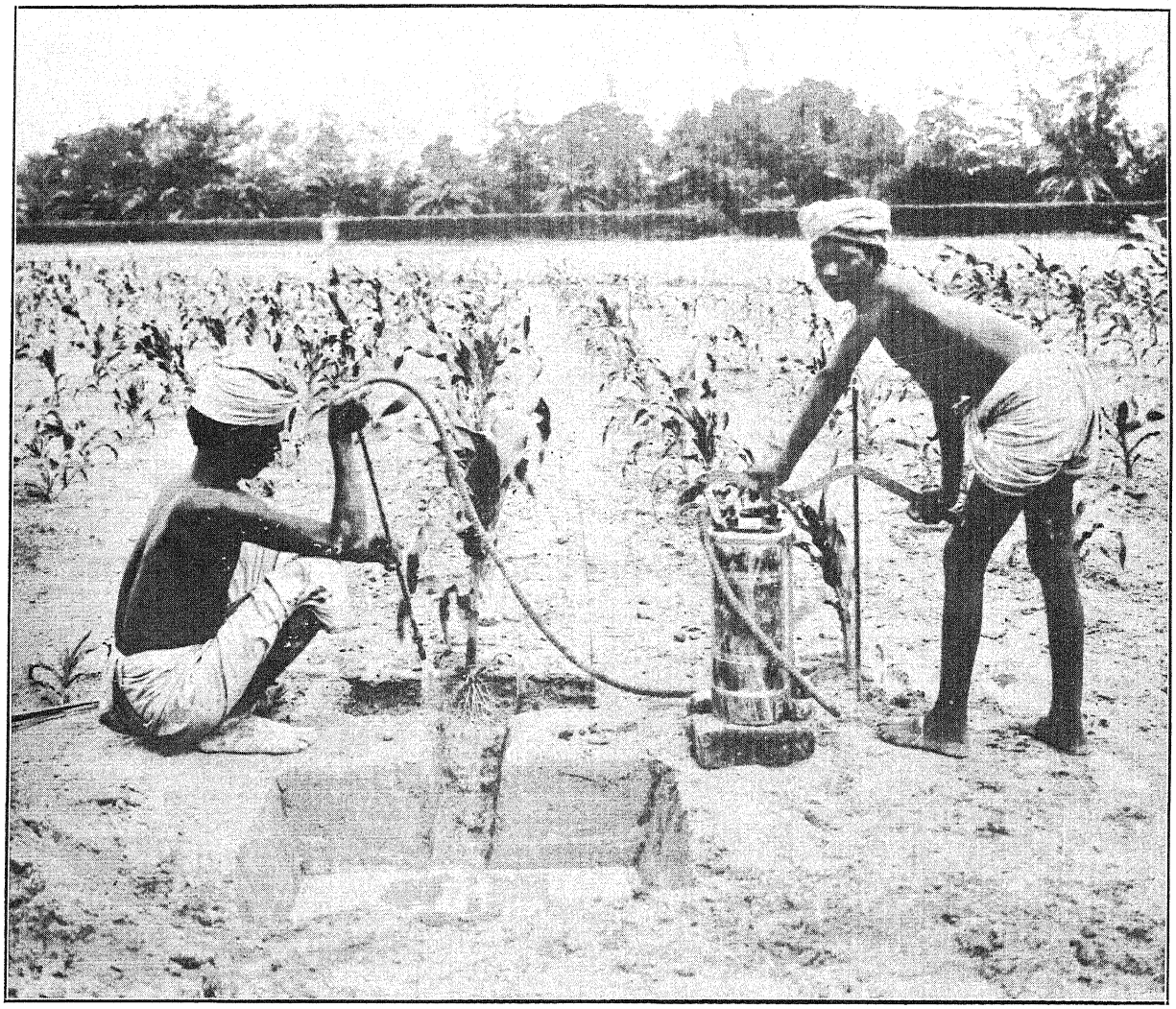
plants to be examined; the dimensions of the trench varied according to the conditions, but generally trenches $7' \times 3' \times 5'$ were found suitable.

There are two distinct methods which have been used by different investigators for uncovering root-systems. The first is by removing the soil with a stream of water from a reservoir as employed by Hays [1889] in washing the roots of corn; and by other workers like King [1893], Ten Eyeck [1900], Sheppard [1905], etc., with various modifications for different crops and trees. The second consists in uncovering the root-system with the help of a small hand-pick with a cutting edge at one end and a long tapering point at the other. This method has been adopted by Weaver [1926, 2] and his co-workers at Nebraska and other stations in the United States of America.

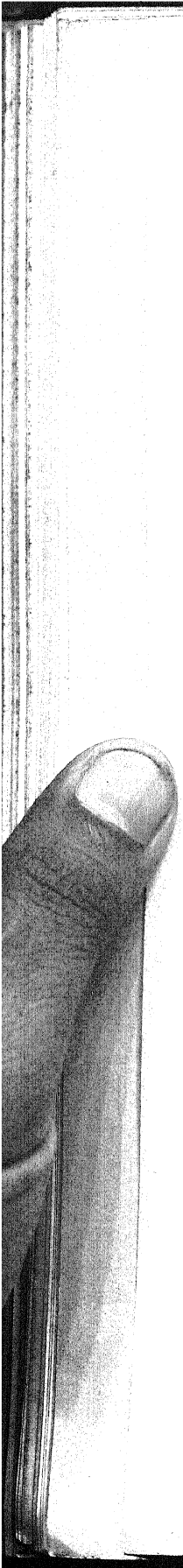
The latter method was tried for some time but did not work successfully. Not only did it require considerably more time and energy and a great deal of patience, but to trace the final rootlets and predict their course in the soil was found practically impossible; moreover, the rootlets being very fine were liable to be cut. There was no difficulty, however, in following the first method which is much less laborious and works quite well in hard as well as sandy soils. This method has been in use in Pusa since a very long time. A gentle stream of water from a knapsack sprayer uncovers the roots very satisfactorily (Plate XI). The roots are retained in their normal position by the anchoring root hairs and minute branches of the rootlets. To have a general idea of the extent of the root-system, washing is done rapidly downwards till the maximum depth to which the vertical roots penetrate is reached, the character of the ultimate branches and maximum depths is recorded and then the upper portions of the vertical root-system and the shallow root-system are washed and studied. In this way the problem of removing the water from the trench does not face the worker. The deeper roots which are rather few in number and sparsely branched, are studied first when there is very little water in the trench. The water that collects later, on washing the upper roots, does not then interfere with the study of the upper root-system.

III. General Description.

The root system in all types of barley studied here consisted of two sets of roots —the shallow roots and the deep roots. At the base of each tiller both these kinds of roots arose. One set of roots went horizontally or a little obliquely in the upper region of the soil, forming the shallow root-system and the other set took a downward course and formed the deep root-system. The roots forming the shallow root-system extended out horizontally or obliquely in all directions from the base of the plant, their maximum length ranged from 22 cm. to 48 cm. in various types and gave out laterals throughout their course. The laterals were 9 cm. to 16 cm. long and were branched and re-branched in turn, forming a dense network in the first one foot or $1\frac{1}{2}$ feet of the soil. They extended in all directions from the base of the plant, their ends often reaching the very surface of the soil.



METHOD OF WASHING ROOTS.



The roots constituting the deep root-system took up a more or less tortuous course downwards and were freely branched, the branches running horizontally for some distance and then going irregularly downwards. The depth to which these branches were quite abundant is termed the working depth and varied with different types from 50 cm. to 120 cm. The maximum depth to which the majority of the roots of this set reached was 100 cm. to 170 cm. in various types, but the maximum depth of the longest roots was recorded as deep as 190 cm. The last 10 to 25 cm. of these roots were very thin and rarely branched; if branches ever occurred they were not more than a few centimetres long.

In general the roots of the shallow set were finer than the roots of the deep set.

IV. Classification of Root Types.

The different kinds of root-systems met with in the Pusa barley types have been classified into four groups according to the character of the shallow and the deep roots and to the direction of the shallow roots. These groups are as follows :—

Type of root-system	Shallow roots	Deep roots
I Mesophytic	Well developed, profusely branched and horizontal in surface soil.	Do not penetrate very deep.
II Semi-mesophytic . . .	A little less developed than I, but quite vigorous and horizontal.	Go a little deeper than I but not well branched.
III Semi-xerophytic . . .	Quite well developed but given at obtuse angle to tillers, *i.e.*, direction oblique.	Well developed and deep penetrating.
IV Xerophytic	Poorly developed and oblique .	Larger in number and very deep penetrating.

I. Mesophytic type of root-system. Barley Types with well developed and profusely branched shallow roots taking a more or less horizontal course to the surface of the soil and a poorly developed deep set of roots. The shallow roots spread more or less horizontally in all directions from the base of the plant in a radius of 35 to 50 cm. and a depth of 20 to 30 cm. The working depth ranges from 50 to 90 cm. According to the working depth, this group may further be sub-divided into two groups :—

(1) Mesophytic—A.

(2) Mesophytic—B.

In the former the working depth varies from 78 to 90 cm. and in the latter from 50 to 60 cm. The maximum depth of the deep roots does not exceed 130 cm. in

both the sub-groups and their number and the number of their branches is usually small. (Plate XII, fig. 1.)

Barley Types in Mesophytic A—T. 24, 21, 20, 12 and 7.
„ Types in Mesophytic B—T. 1, 2, 5, Chevaliar and Chevaliar-Archer.

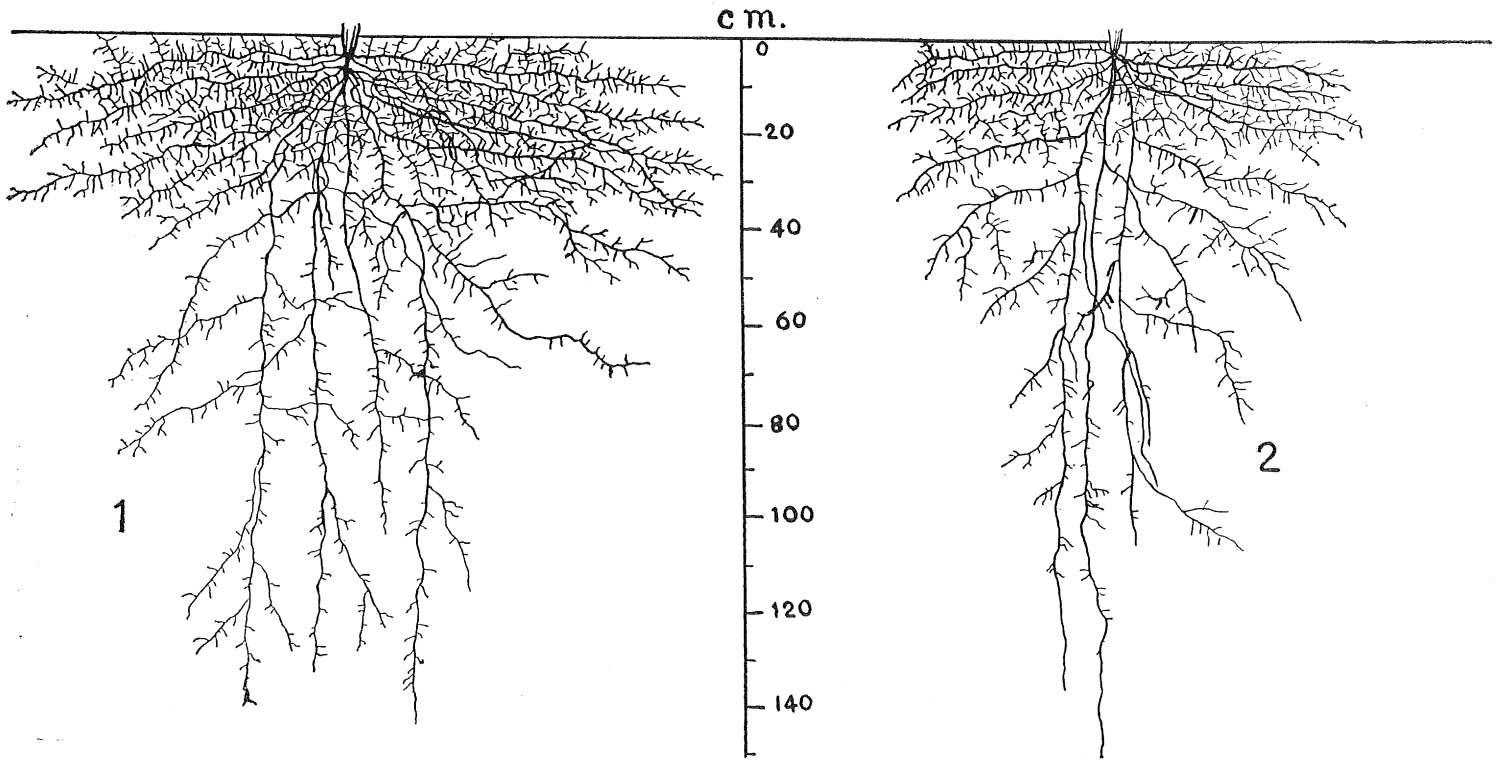
Thus the mesophytic type of root-system may be defined as that which shows a luxuriant growth of shallow roots in the upper regions of the soil on which it depends for the moisture supply.

II. *Semi-Mesophytic type of root-system.* Barley Types with the shallow root-system somewhat less developed and spreading horizontally in the surface of the soil and the deep root-system rather better developed than in the mesophytic type. Shallow roots are given out at right angles to the tillers as in the first type of root-system, their length varying from 26 to 40 cm. The branches of these shallow roots are also at right angles to the main axis and are fewer and shorter than in the former type. The working depth is more or less the same as in the previous case, but the soil is not so densely filled with roots as in the former. The deep vertical roots go deeper in some cases, reaching as deep as 145 cm. and show a good deal of branching (Plate XII, fig. 2).

Barley Types in this group—T. 6, 18, 9, 13 and cultures 15-10, 14-1 and C-1. Here the root development is not only confined to the upper layers of the soil but to some extent the roots traverse the deeper layers as well.

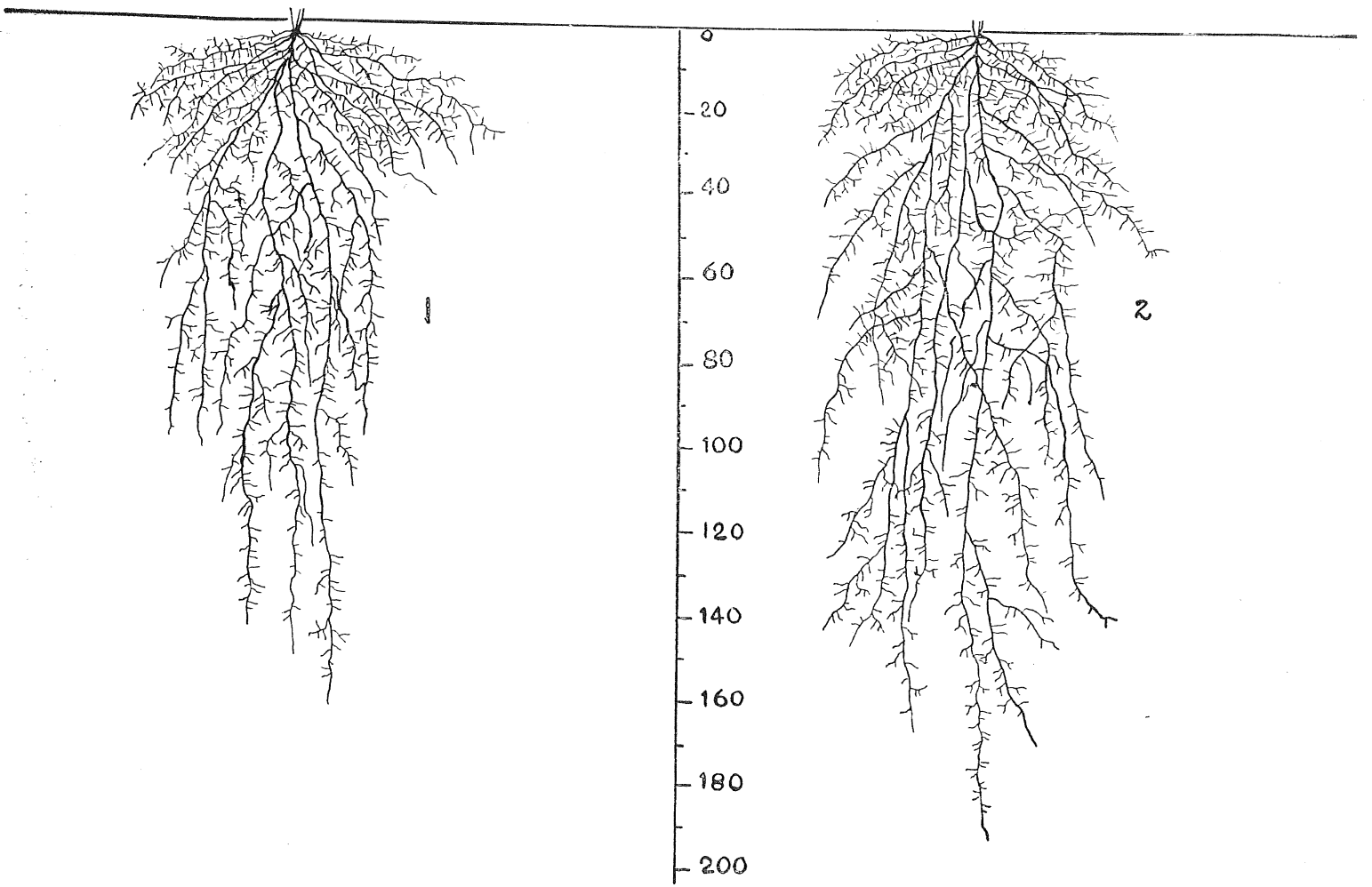
III. *Semi-xerophytic type of root-system.* In this type the shallow roots are quite well developed but are given out at an obtuse-angle to the tillers, thus traversing the soil obliquely ; branching is quite abundant. Accompanying this well-developed oblique shallow root-system is an equally well-formed vertical set of deep roots ; the depth of the shallow roots as well as the deep roots is more than in the previous two types of root-systems. The uppermost layers of the soil seldom contain any root branches. (Plate XIII, fig. 1). Types 22, 19, 16 and 7 and cultures S-1 and S-2 are included in this group. These types depend for their water supply on the lower layers of the soil more than the upper layers. The surface layers are not at all traversed by the roots. These types exhaust both the upper and lower strata of the soil, leaving of course the first few inches.

IV. *Xerophytic type of root-system.* In this type the shallow root-system is very poorly developed, shows little branching and the direction is oblique ; that is, the roots are given off at an obtuse-angle to the tillers. The deep roots are longer and larger in number, penetrating as deep as 170 to 190 cm. in some types. The working depth is greater than any of the first mentioned three types, varying from 90 cm. to 110 cm. (Plate XIII, fig. 2). Types 23, 18, 17, 15, 11 and 4, and Culture 1-10 are grouped in this division. These types more or less depend entirely for their water-supply on the lower layers of the soil, and very scarcely affect the upper layers.



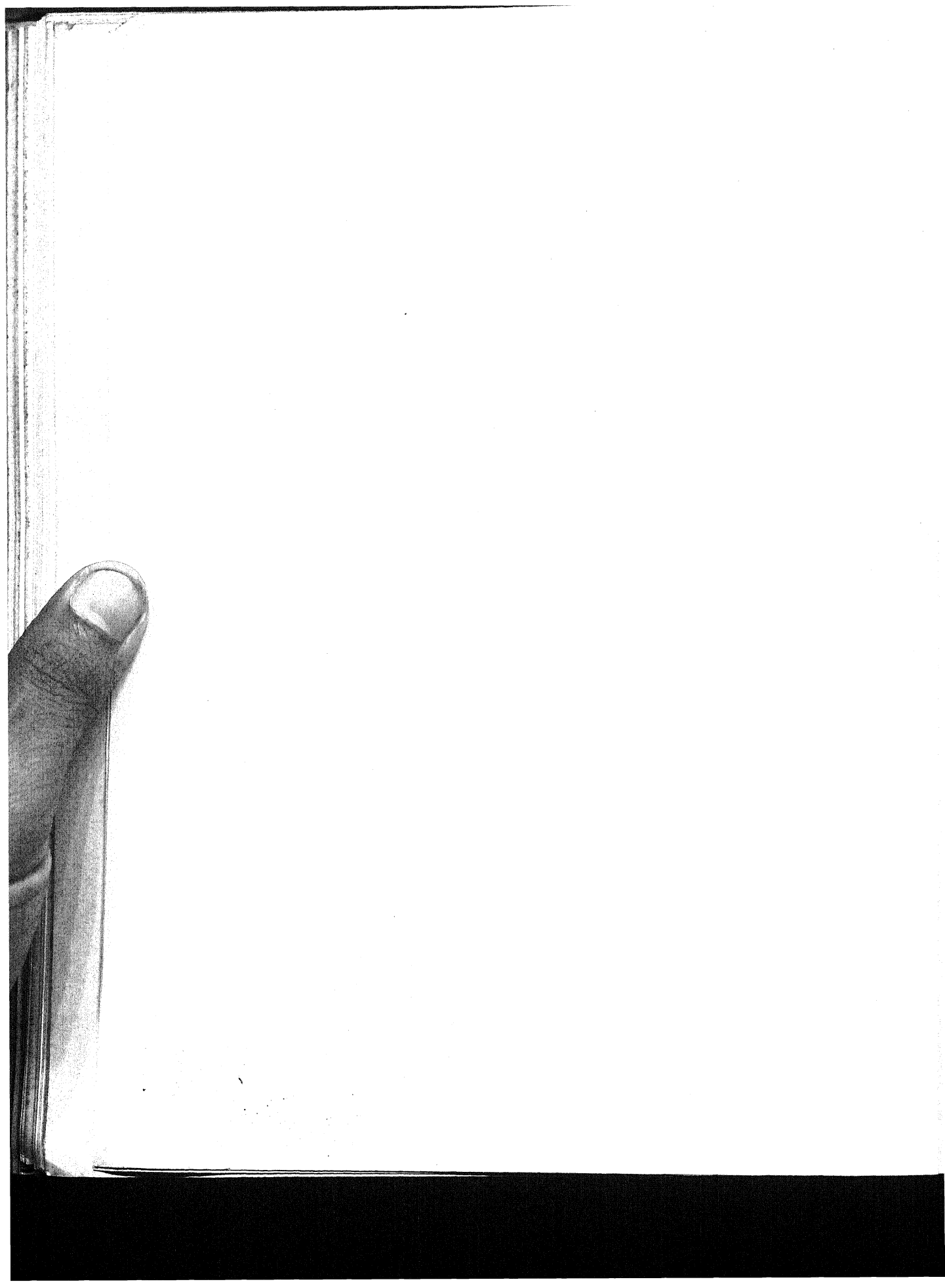
TYPES OF ROOT-SYSTEM IN BARLEY.
1—Mesophytic; 2—Semi-mesophytic.

PLATE XII.



TYPES OF ROOT-SYSTEM IN BARLEY.
1—Semi-xerophytic ; 2—Xerophytic.

PLATE XIII.



V. Relation to Locality.

The habits of roots as those of shoots of a plant are no doubt modified to some extent by environmental factors, but they are primarily governed by the hereditary growth characters of the type to which the plant belongs, and only those types which are best suited morphologically and physiologically for a certain tract will be able to continue their existence during the course of evolution in that tract.

This fact has been very well illustrated in the present study of the root-systems in barley types. Types like T. 24, 21, 20, 12 and C-1, which have a very well-developed root-system, with their shallow roots growing at right angles to the tiller and traversing the surface soil somewhat in the horizontal direction, all belong to Bihar. In all these cases the set of deep roots is comparatively poorly developed. This shallow-rooting habit has been attributed to bad aeration of the Bihar alluvium by Howards [1917] ; what other factors are responsible for it deserves further investigation. Water-content of the soil appears to be an important factor. There is enough moisture in the upper layers of the soil for the maintenance of the plant, so the necessity for the roots to go deep does not arise. Another point which is worth notice is that out of the types in the Mesophytic B group which confine the development of their shallow roots to very superficial layers of the soil, Type 5 belongs to Nepal and the other four are exotics imported from Europe. Types placed in the Semi-Xerophytic and Xerophytic groups of root-systems which possess a very deep penetrating set of vertical roots and whose shallow roots instead of going at right angles to the tillers make an obtuse angle and traverse an oblique course in the soil, leaving the surface layers of the soil altogether free, have all originated from seed brought from drier parts of the country like Ajmere, Larkana, Ferozepur, Ludhiana, Lyallpur and Saharanpur. The oblique and downward direction of the shallow set of roots and the great length and branching of the deep roots indicate the tendency of the roots to go down in search of moisture to the deeper layers of the soil, owing to lack of water in the upper layers which are apt to dry in the hot season. Besides this where more sand occurs greater penetration results and plants root deeper. [Weaver, 1924.]

Briefly, shallow-rooted types belong to localities where there is abundance of moisture in the surface layers of the soil, and deep-rooted types with oblique shallow roots are the inhabitants of drier regions where surface layers lack sufficient moisture.

VI. Relation to Maturity.

The deep-rooting habit and a long growing season and the shallow-rooting habit and a short growing period go hand in hand [Weaver, 1926, 1]. It has been observed that the barley types which are shallow-rooted are generally early ripening taking from 60 to 77 days to flower, with the exception of 5 types placed in Mesophytic-B which take 95 to 110 days to flower. These have originated from cold tracts, where the growing season is longer and naturally flowering is late. Types which are

deep-rooted and whose shallow root-system is rather poor and goes obliquely are late in maturity, taking from 78 to 105 days or more to flower. Barley Types like T. 11, T. 15, T. 17 and T. 5 in which the shallow root-system is very poor take the longest period among the Indian types to head out. The only deep-rooted type which is early flowering is Type 7 ; but in this, however, the shallow roots, although oblique, are very well-developed, and help in inducing early flowering.

The physiological explanation of this early and late flowering of the shallow and deep-rooted types, respectively, lies in the fact that the Mesophytic A and Semi-mesophytic groups where the shallow root-system is well-developed, take advantage of the abundant food and moisture supply of the upper layers of the soil and thus complete their vegetative growth much earlier, after which the whole energy of the plant is diverted to its reproductive phase. The deep-rooted types (xero and semi-xerophytic) which cannot take advantage of the nutrients in the upper layer due to their week shallow root-system have to wait till the vertical deep roots have attained their maximum growth, thus delaying the date of flowering. It has been observed by Lees [1927] that in oats and wheat the roots increase in length directly with lateness of ripening.

VII. Relation to Habit.

All the barley types when mature become erect in form but differences into erect, semi-erect, bushy and spreading are quite distinct during the early periods of growth. An effort has been made to establish if any relation exists between early habit of the tops and the nature of the root-system in the various types. The types which are generally deep-rooted and whose shallow roots are poor and spreading obliquely are generally bushy or spreading in early habit, with the exception of Types 7 and 22 which are semi-erect. These types, moreover, are late in maturity.

The less deep-rooted types with well-developed shallow roots spreading horizontally with the surface of the soil are generally erect or semi-erect in form in their early habit and flower at an early date.

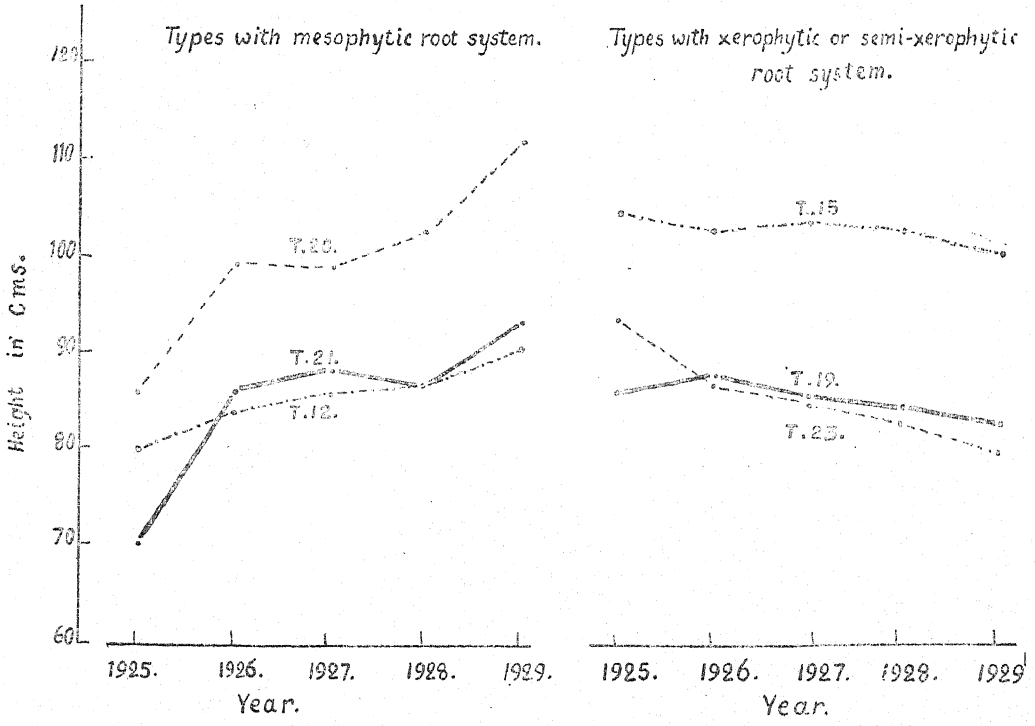
In other words, deep-rooted types are bushy or spreading in early habit, while shallow-rooted types are erect or semi-erect in form in their early stages.

VIII. Relation to Height.

It is a common belief that the root-system is the image of the shoot-system and the greater the depth of the roots the greater is the height of the shoots. A comparative study of the root-system of the various types of barley, however, does not substantiate this view. There are types with deep roots and short tops and these are not uncommon. The only thing that may be said about the relation between the height of the tops and the depth of the roots is this that types whose maximum root depth is more than 150 cm. are at least 90 cm. in height with the exception of Type 7 whose maximum depth is 150 cm. and the average height of its tops is only 79 cm. It should not be understood that all types which are 90 cm. or more in

height are necessarily deep-rooted, for there are types like Types 24, 20 and 13 which are not very deep-rooted but whose tops attain quite good heights. Weaver [1926, 3] has observed that shoot development and yield are correspondingly reduced with the depth of root penetration in barley.

Another fact which has been noticed is that types with mesophytic type of root system which are well adapted to Pusa conditions have steadily gained in height, and those in which the root-system is of the xerophytic or semi-xerophytic nature have either decreased in height or have hardly maintained the same. This is well illustrated by the following graph which shows Types 12, 20 and 21 (mesophytic) showing gradual increase in their heights and Types 15, 19 and 23 (xerophytic or semi-xerophytic) in which the heights have either decreased or have remained almost the same.



GRAPH SHOWING THE RELATION OF HEIGHT AND TYPE OF ROOT SYSTEM IN DIFFERENT YEARS.

FIG. 1.

IX. RELATION TO YIELD.

Differences of yield in different types may be due to a number of factors, but the accompanying data show clearly that there is a definite correlation between the yielding capacity of a type and the nature of its root-system. Types placed in the

first group of mesophytic-A and semi-mesophytic root-systems are amongst the highest yielders at Pusa. They possess a very well-developed shallow root-system, their roots extending from 30 to 40 cm. on all sides of the plant and branching profusely. On the other hand, types placed in the second group with semi-xerophytic and xerophytic types of root-systems are generally low yielders with the exception of Types 7 and 22. Although these types are very deep-rooted, they possess a strongly developed shallow system which, however, differs from the shallow system of the first group by the oblique direction of its roots.

It should not be understood from the above statement that all deep-rooted types must be low yielders everywhere. These types may give much better results in drier tracts of the country and the shallow-rooted types which top the list in yield trials under Pusa conditions may prove an utter failure in tracts where the moisture is not enough in the upper layers and the growing season is long. The physiological explanation of the fact that types which have a well-developed root-system and a poor deep penetrating root-system do not do well in dry tracts, is that at the time of flowering the season becomes very hot, the surface layers in which the roots are most abundant become devoid of moisture and there are not enough roots in the lower layer which would supply the needs of the plant during the grain-formation period ; consequently the yield suffers heavily.

The reason of low yields of the deep-rooting types in Bihar may be sought in the fact that their shallow root-system being poor they cannot take full advantage of the moisture in the upper layers and it takes a long time for the deep roots to attain their full growth. By the time the latter are in a position to supply the plant with its essential ash constituents and water, the hot winds set in, the balance between the absorbing and transpiring functions cannot be maintained, the shoots and the leaves begin to dry up, the supply of water and the mineral substances from the soil is hindered and hence the types suffer in their yielding capacity.

X. Summary.

1. Root-systems of 30 types of barley were studied when the plants were mature and ready for harvest.

2. Hays' method of washing the roots with a stream of water from a knap-sack sprayer was found suitable.

3. Root-system in each type consisted of two sets of roots, the shallow roots and the deep roots.

4. Each type could be placed according to the character of its shallow roots and deep roots and the direction of the shallow roots, in one of the following four classes :—

I. *Mesophytic type of root-system*—shallow roots well-developed and given off at right angles to the tillers ; deep roots comparatively poor.

(i) *Mesophytic-A.*—working depth 80 to 90 cm.

(ii) *Mesophytic-B.*—working depth 50 to 60 cm.

II. *Semi-mesophytic type of root-system*—shallow roots poorer than the first; deep roots poor but better than the first in number and branching.

III. *Semi-xerophytic type of root-system*—shallow roots well-developed, given off obliquely downwards; deep roots greater in number than I and II and longer.

IV. *Xerophytic type of root-system*—shallow root-system poor; deep root-system generally deep penetrating and well-formed.

5. Shallow-rooted types with the shallow roots spreading at right angles to the tillers generally belong to Bihar or localities with abundant soil-moisture. Deep-rooted types with poorly developed shallow roots which go out obliquely at an obtuse angle to the tillers, have originated from the seed brought from drier tracts of the United Provinces, Punjab, Sind and Rajputana.

6. Shallow-rooted types are earlier in maturity and date of flowering, while the deep-rooted types take a longer period.

7. Shallow-rooted types are erect or semi-erect in early habit, while the deep-rooted types have a tendency to be spreading or bushy in the early days of their growth.

8. There is no definite relation between the height of the tops and the depth of the roots in different types. All deep-rooted types do not possess tall shoots and all shallow-rooted types are not short-shooted.

9. Shallow-rooted types are amongst the highest yielders at Pusa and the deep-rooted types with poor shallow roots do not fare well in this place.

XI. Description of Root Habit in Barley.

I. Mesophytic—A.

Type 24. Distinction into shallow set and deep set of roots is very definitely marked; shallow root-system better developed and goes horizontally in the surface soil; vertical root-system is poorly developed; can work well only in such conditions as prevail in Bihar alluvium.

	cm.
Deep roots—	
Maximum depth	105
Working depth	80
Shallow roots—	
Spread	36
Depth	23

Type 21. Shallow root-system very well developed and profusely branched in first 1½ ft. of the soil; direction of the shallow roots is somewhat at right angles to the tillers; deep root-system is not well developed; there is very sparse branching after 90 cm.

	cm.
Deep roots—	
Maximum depth	130
Working depth	85
Shallow roots—	
Spread	48
Depth	29

Type 20. Shallow root-system is very well developed and is horizontal in direction to the surface soil; vertical roots are not so well developed and are less branched.

	cm.
Deep roots—	
Maximum depth	120
Working depth	78
Shallow roots—	
Spread	38
Depth	22

Type 14. Shallow root-system is very vigorous and profusely branched, roots going at right angles or so to the tillers; vertical root-system is rather poor in development as compared with the shallow; appears to be a promising type worth giving a trial in Eastern United Provinces and Bihar.

	cm.
Deep roots—	
Maximum depth	128
Working depth	88
Shallow roots—	
Spread	44
Depth	30

Type 12. Shallow root-system is very well developed and spreads very profusely all around the plant; direction of the shallow roots is horizontal; vertical root-system is less developed than the shallow root-system, but is quite vigorous.

	cm.
Deep roots—	
Maximum depth	130
Working depth	91
Shallow roots—	
Spread	42
Depth	19

Appears to be quite suitable for Eastern United Provinces and Bihar.

MESOPHYTIC—B.

Type 5. Shallow root-system is very well developed, roots go more or less horizontally in the soil, traverse a long distance tortuously in the upper layers; vertical root-system is meagre in development.

	cm.
Deep roots—	
Maximum depth	85
Working depth	52
Shallow roots—	
Spread	40
Depth	22

Type 2. A selection from European barley ; shallow root-system is only poorly developed ; vigorous roots are confined to the first 15 cm. of the superficial soil only ; deep root-system is also poor in development, but better than Chevalier.

	cm.
Deep roots—	
Maximum depth	122
Working depth	62
Shallow roots—	
Spread	34
Depth	26

Type 1 (Two-rowed). Roots well developed in the first one foot of the soil ; shallow root-system more vigorous than the vertical which is rather poor ; shallow roots take up a more or less horizontal direction to the tillers.

	cm.
Deep roots—	
Maximum depth	112
Working depth	50
Shallow roots—	
Spread	35
Depth	23

Chevalier. The shallow root-system is very well developed ; filling up the $1\frac{1}{4}$ ft. of the top soil with numerous roots ; direction of shallow roots is parallel with surface layers of the soil ; the deep roots are rather poorly developed and less deep.

	cm.
Deep roots—	
Maximum depth	95
Working depth	58
Shallow roots—	
Spread	50
Depth	28

Chevalier-Archer. Shallow root-system moderately developed with slightly oblique shallow roots ; vertical root-system shows poor development, but better than Chevalier.

	cm.
Deep roots—	
Maximum depth	125
Working depth	60
Shallow roots—	
Spread	45
Depth	29

II. Semi-Mesophytic.

Type 13. Shallow root-system is better developed than the deep root-system the direction of the shallow roots is at right angles to the tillers ; general outlook of the root-system is not very promising, branching rather poor.

	cm.
Deep roots—	
Maximum depth	130
Working depth	85
Shallow roots—	
Spread	38
Depth	22

Type 9. Shallow root-system quite well developed and slightly oblique in direction nearly at right angles to the tillers ; deep roots are also quite vigorous, but poorer than the shallow root-system.

	cm.
Deep roots—	
Maximum depth	140
Working depth	89
Shallow roots—	
Spread	44
Depth	35

Root-system on the whole very promising, may suit Bihar and United Provinces conditions remarkably well.

Type 8. Shallow root-system is quite well developed and is more or less at right angles to the tillers ; deep set of roots is equally well formed.

	cm.
Deep roots—	
Maximum depth	140
Working depth	98
Shallow roots—	
Spread	39
Depth	25

Type 6. Shallow root-system is better developed than the deep vertical root-system which is quite deep but sparsely branched ; direction of shallow roots is at right angles to the tillers ; root-system is on the whole less vigorous and meagrely branched.

	cm.
Deep roots—	
Maximum depth	137
Working depth	88
Shallow roots—	
Spread	30
Depth	22

Culture 15-10. Shallow root-system poorly developed, but is near the surface running at right angles to the tillers; deep set of roots moderately developed; not very promising on the whole.

	cm.
Deep roots—	
Maximum depth	140
Working depth	90
Shallow roots—	
Spread	35
Depth	23

Culture C-1. Shallow root-system is very well developed and the shallow roots are only slightly oblique; deep vertical root-system is also quite vigorous, but the shallow system is more prominent.

	cm.
Deep roots—	
Maximum depth	145
Working depth	102
Shallow roots—	
Spread	44
Depth	32

A promising type of root-system—may suit eastern United Provinces and Bihar.

Culture 14-1. Shallow root-system is poor and less branched; roots going somewhat horizontally in the few inches of surface soil; deep root-system is more vigorous, the deepest roots penetrating as deep as 145 cm.

	cm.
Deep roots—	
Maximum depth	145
Working depth	102
Shallow roots—	
Spread	28
Depth	22

III. Semi-Xerophytic.

Type 22. Shallow root-system is quite well formed but is somewhat oblique in direction and less vigorous than the vertical deep root-system; roots of the deep set penetrate deep but are not so profusely branched.

	cm.
Deep roots—	
Maximum depth	170
Working depth	120
Shallow roots—	
Spread	40
Depth	29

This type of root-system is very desirable in tracts where soil and atmospheric conditions are uncertain ; it will do well in dry as well as wet soils.

Type 19. Shallow root-system is very vigorous, but the direction of the shallow roots is very oblique ; few branches occur in the upper layers of the soil ; vertical root-system is also well developed ; root-system quite vigorous on the whole.

	cm.
Deep roots—	
Maximum depth	157
Working depth	101
Shallow roots—	
Spread	45
Depth	40

Type 16. Shallow root-system is quite moderately developed ; accompanied with this is a well-developed and profusely branched deep set of roots ; direction of shallow roots is rather oblique.

	cm.
Deep roots—	
Maximum depth	155
Working depth	101
Shallow roots—	
Spread	38
Depth	32

Type 7. Shallow root-system is very well developed and profusely branched ; the direction of the shallow roots is *characteristically oblique* ; along with this the vertical root-system is also very vigorous and deep penetrating ; appears to be a promising type, very well suited to dry conditions and apt to give quite tolerable results in wet conditions.

	cm.
Deep roots—	
Maximum depth	151
Working depth	96
Shallow roots—	
Spread	42
Depth	31

Culture S-1. Shallow root-system is quite vigorous but oblique in direction ; this oblique direction of the shallow roots is very well marked ; the deep roots are deep penetrating but not so well branching.

	cm.
Deep roots—	
Maximum depth	162
Working depth	90
Shallow roots—	
Spread	44
Depth	35

Culture S-2. Shallow root-system is vigorous but markedly oblique in direction; vertical root-system quite deep penetrating.

	cm.
Deep roots—	
Maximum depth	182
Working depth	102
Shallow roots—	
Spread	44
Depth	35

IV. XEROPHYTIC.

Type 17. Shallow root-system is less developed than the deep root-system and is oblique in direction; root-system on the whole is feeble in development and vigour.

	cm.
Deep roots—	
Maximum depth	145
Working depth	90
Shallow roots—	
Spread	28
Depth	26

Type 18. Shallow root-system poorly developed with somewhat oblique shallow roots; deep roots more vigorous and deep penetrating.

	cm.
Deep roots—	
Maximum depth	158
Working depth	100
Shallow roots—	
Spread	28
Depth	25

Type 23. Shallow root-system is very poorly developed and shows little branching; the direction is oblique; vertical root-system is very vigorous and well formed.

	cm.
Deep roots—	
Maximum depth	158
Working depth	110
Shallow roots—	
Spread	26
Depth	22

May do well in drier parts of the country where zerophytic conditions prevail.

Type 15. Shallow root-system is poor, shows little branching in the upper layers of the soil and is oblique in direction; vertical roots are well developed.

	cm.
Deep roots—	
Maximum depth	165
Working depth	95
Shallow roots—	
Spread	26
Depth	28

Type 11. Shallow root-system is rather poor and its roots go obliquely in the soil, the surface 5 to 10 cm. of the soil contains no rootlets ; the vertical root-system is very strongly developed and well branched and vigorous.

	cm.
Deep roots—	
Maximum depth	147
Working depth	95
Shallow roots—	
Spread	31
Depth	28

Type 4. Shallow roots quite well developed but the direction is markedly oblique ; deep roots do not go very deep. Upper layers of the soil have few roots.

	cm.
Deep roots—	
Maximum depth	105
Working depth	70
Shallow roots—	
Spread	30
Depth	27

Culture 1-10. Shallow root-system is comparatively poor in development and roots of this set run obliquely in the soil, leaving the upper few inches without any branches ; the vertical set of deep roots is very well developed and vigorous in form.

	cm.
Deep roots—	
Maximum depth	157
Working depth	110
Shallow roots—	
Spread	36
Depth	27

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APPENDIX A.

Summary of observations in Barley Types.

Name of culture	Type No.	Type of root-system	Shallow roots		Deep roots		Locality of origin	Early habit	Maturity i.e. No. of days taken to flower		Height cm.		Yield	
			Spread in cm.	Depth in cm.	Working depth cm.	Maximum depth cm.			In 1929	Average of 6 years	In 1929	Average of 6 years	Per line in 1929	Per bed 4′×50′ in 1928
													oz.	lb.
Ramdana . .	T. 24	Mesophytic-A .	36	23	80	105	Local . .	S E	57	62	91·4	92·0	18·7	18
B-4 . . .	T. 21	Do. .	48	29	85	130	Do. . .	S E	69	72	92·8	83·0	22	31
23-10 . .	T. 20	Do. .	38	22	78	120	Patna (Bihar) .	E	67	73	111·8	99·0	18·3	29
20-7 . .	T. 14	Do. .	44	30	88	128	Hardoi (U.P.) .	E	62	61	92·2	79·0	15·0	24
22-2 . .	T. 12	Do. .	42	19	91	130	Arrah (Bihar) .	E	67	71	90·4	85·0	16·7	21
Nepal type .	T. 5	Mesophytic-B .	40	22	52	85	Nepal . .	E	89	..	88·5	..	..	..
2-rowed C .	T. 2	Do. .	34	26	62	122	Selection from European oat sample.	E	107	..	70	..	..	..
2-rowed B. .	T. 1	Do. .	35	23	50	112	Do. .	S E	100	..	57	..	..	..
Chevalier . .	..	Do. .	50	28	58	95	European .	E	105	..	80	..	..	..
Chevalier-Archer	..	Do. .	45	29	60	125	Do. .	E	108	..	78	..	..	..
17-2 . .	T. 13	Semi-mesophytic	38	22	85	130	Bareilly (U.P.).	S E	74	78	92·6	91	10·2	23
21-1 . .	T. 9	Do. .	44	35	89	140	Cawnpur (U.P.)	E	74	77	91·1	83	12·3	29
9-5 . . .	T. 8	Do. .	39	25	98	140	Hapur (U.P.) .	S E	67	75	86	81	13·3	25
10-10 . .	T. 6	Do. .	30	22	80	137	Khurja (U.P.) .	E	69	74	78·8	76	11·3	18
C-1 . . .	..	Do. .	44	32	102	145	Local . .	E	74	77	106·4	97	18·7	24
15-10 . .	..	Do. .	35	23	90	140	Hathras (U.P.).	S E	68	69	85	82	9·2	19
14-1 . .	..	Do. .	28	22	102	145	Kasganj (U.P.)	E	69	69	83	79	10·6	18
16-8 . .	T. 22	Semi-Xerophytic	40	29	120	170	Agra (U.P.) .	S E	77	79	99·4	89	17	23

S. E. = Semi-erect. E. = Erect. B. = Bushy. Spr. = Spreading.

Summary of observations in Barley Types—contd.

Name of culture	Type No.	Type of root-system	Shallow roots		Deep roots		Locality of origin	Early habit	Maturity *i.e.* No. of days taken to flower		Height cm.		Yield	
			Spread in cm.	Depth in cm.	Working depth cm.	Maximum depth cm.			In 1929	Average of 6 years	In 1929	Average of 6 years	Per line in 1929	Per bed 4′×50′ in 1928
													oz.	lb.
18-3 . .	T. 19	Semi-Xerophytic .	45	40	101	157	Gola-Gokaranath (U.P.).	B	88	87	83	85	10·6	14
19-2 . .	T. 16	Do. .	38	32	101	155	Sitapur (U.P.) .	B	82	84	97·5	91	12	26
24-6 . .	T. 7	Do. .	42	31	96	151	Ajmer (Rajputana).	S E	68	69	88·6	77	21·7	22
S-1 . . .	..	Do. .	44	35	90	162	Selection (stray)	Spr.	82	83	98	..	12	..
S-2 . . .	..	Do. .	38	35	102	182	Do. .	B	79	81	100	..	13·3	..
12-5 . .	T. 23	Xerophytic .	26	22	110	158	Kosi . .	B	77	79	80	80	8·0	12
5-6 . . .	T. 18	Do. .	28	25	100	158	Saharanpur (U.P.).	B	77	83	85	86	10·6	15
4-2 . . .	T. 17	Do. .	28	26	90	145	Ludhiana (Punjab).	B	77	81	93·6	93·0	9·6	12
28-8 . .	T. 16	Do. .	26	28	95	165	Larkana (Sind)	B	100	100	105·2	103	7·7	12
B-Ferozepur .	T. 11	Do. .	31	28	95	147	Ferozepur (Punjab).	B	98	94	108·6	..	8·8	..
1-10 . .	..	Do. .	36	27	110	157	Larkana (Sind)	Spr.	77	89	104·4	105	9·2	13
B-Aligarh .	T. 4	Do. .	30	27	70	105	Aligarh (U.P.) .	B	105	..	61	..	..	..

S. E.=Semi-erect. E.=Erect. B=Bushy. Spr.=Spreading.

SOME BREEDING INVESTIGATIONS ON *TORIA* (*BRASSICA NAPUS* L. VAR. *DICHOTOMA* PRAIN) AND *SARSON* (*BRASSICA CAMPESTRIS* L. VAR. *SARSON* PRAIN).

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(With Plates XIV and XV and one text-figure.)

I. Preface.

Work on *toria* and *sarson* in the Punjab, an aspect of which forms the subject matter of this publication, was originally started in the year 1910 by Mr. D. Milne, C.I.E., then, and for a long time after, Economic Botanist to Government, and now Director of Agriculture, Punjab. He collected a number of local varieties of these crops and introduced into the Province two varieties of Japan rape, which later found great favour with farmers for certain special purposes. Observations made on the above collection by him and author No. 1 of this paper, who worked under Mr. Milne for several years, had shown that considerable crossing occurred in the field in these two crops and that it was very difficult to keep the various varieties pure. However, as work on other more important crops such as cotton, wheat, barley, gram, etc., claimed priority of attention in those days, no detailed breeding investigations of the type recorded in this publication could then be undertaken. On the appointment of authors Nos. 2 and 3 about the year 1926, work on these two crops was started in detail and further developed, record of which is to be found in the *Reports on the operations of the Department of Agriculture, Punjab*, Part II (Annual Record of Experimental Work). Since 1929, this work has been in charge of author No. 1 and the account given in the present publication is an attempt to record the findings up-to-date in a combined form. As little record of previous work is available on these two crops, it is hoped that the present work would be a useful contribution towards the elucidation of breeding problems connected with them.

Our thanks are due to Mr. T. A. Miller Brownlie, Principal, Punjab Agricultural College, Lyallpur, who kindly arranged for Mr. Nasir to do the photographic work for us. His help has been most valuable.

II. Introduction.

Of the oil-seed crops grown in the Punjab, *toria* and *sarson* are by far the most important. *Toria* is chiefly grown in the canal colonies and occupied an area of 622,621 acres in the year 1928-29, out of which 511,621 acres were irrigated. *Sarson* is sown almost all over the Province except in the hills. The area under this crop is not separately recorded in the official records but is given with *taramira* (*Eruca Sativa*) and *rai* (*Brassica juncea*). The total area under these three crops during the year 1928-29 was 1,099,471 acres, out of which 91,384 acres were irrigated. The fact that *sarson* is generally grown mixed with gram, barley, or wheat, and rarely alone, makes the determination of exact area under this crop rather difficult, but a rough estimate of its acreage in the various districts, which has kindly been supplied by the Deputy Commissioners, is given below in Table I, along with figures for *toria*.

TABLE I.

Acreage under toria and sarson in different Districts in the Punjab during the year 1928-29.

District	Toria			Sarson
	Irrigated	Unirrigated	Total	Total
Hissar	31	1,096	1,127	33,061
Rohtak	..	..	..	10,313
Gurgaon	1	237	238	1,12,727
Karnal	2,756	1,428	4,184	15,300
Ambala	858	1,305	2,163	1,361
Simla	..	..	..	..
Kangra	19	4	23	5,865
Hoshiarpur	95	1,052	1,147	2,471
Jullundur	13	8	21	678
Ludhiana	47	2	49	7,723
Ferozepur	7,707	2,031	9,738	23,661
Lahore	51,192	42,729	93,921	Not available.
Amritsar	40,741	12,557	53,298	2,411
Gurdaspur	10,691	5,110	15,801	12,270
Sialkot	8,486	7,849	16,335	2,906
Gujranwala	30,311	7,331	37,642	5,185
Sheikhupura	68,378	10,744	79,122	3,756
Gujrat	35,978	3,834	39,812	6,481
Shahpur	47,314	2,312	49,626	3,211
Jhelum	..	..	..	5,825
Rawalpindi	..	..	..	10,764
Attock	..	..	..	15,165
Mianwali	..	24	24	4,041
Montgomery	55,432	5,605	61,037	6,530
Lyallpur	121,784	2,265	124,049	12,222
Jhang	6,438	1,680	8,118	483
Multan	23,271	662	23,933	792
Muzaffargarh	78	537	615	1,180
Dera Ghazi Khan	..	125	125	3,572
GRAND TOTAL	511,621	110,527	622,148	305,954

Toria seldom succeeds without irrigation and is more liable to suffer from cold and frost. It is therefore usually sown earlier than other *rabi* (winter) oil-seed crops and is treated as *zaid kharif* (autumn crop). It is generally sown in September and harvested in December-January.

Sarson is usually sown in October-November, almost entirely on unirrigated land, and is harvested in February-March. When sown mixed with other crops, the seed is dropped in furrows made by a plough at intervals of four or five feet throughout the principal crop.

In addition to the extraction of oil from its seed, *sarson* is also used largely as fodder and vegetable. *Toria*, on the other hand, is almost entirely grown for extrac-

tion of oil from its seed. Its importance lies chiefly in the fact that its produce is available for sale to the farmer at a time when he badly needs money for paying off land revenue. (For other details regarding the cultivation, etc., of these crops refer to the "Report on enquiries regarding Indian oil-seed crops" by author No. 1 available from Government printing press, Lahore.)

Nomenclature used. For *toria* and *sarson* a good many botanical names have been used by taxonomists. In naming them *Brassica Napus* L. var: *dichotoma* Prain, and *Brassica Campestris* L. var. *Sarson* Prain, respectively, in this publication, the authors have taken Prain [1898] as their authority, who must have had good reasons for choosing these names.

III. Importance of studying modes of Pollination.

The methods of improvement of a crop from the plant-breeding side depend to a large extent on the mode of pollination obtaining in the crop concerned. The embryo which gives rise to an adult plant results from the fusion of two (male and female) gametes or reproductive cells, whose constitution may be identical or different. In case these two gametes have habitually the same constitution, that is to say, the plant is self-fertilized from generation to generation, the like will produce like. The main process of bringing about improvement in such crop plants is in principle a simple one. It consists in selecting from the local material a large number of plants differing from one another, multiplying their seed, subjecting them to suitable trials and thereafter choosing from among them for introduction into general cultivation one or more turning out to be the most suitable for the conditions obtaining in the locality concerned. In case there is occasional variation from this mode of pollination, the method is still applicable. On the other hand, if the two gametes fusing together are always different in constitution or frequently enough so, that is, a large amount of cross-fertilization occurs in the plant, one generation must be different from the other. In such cases, the evolution of unit species and maintaining them constant from year to year would be extremely difficult and almost impossible in practice; and, from the further fact that almost all such unit species are known to be less vigorous than the naturally occurring heterozygous material, the evolution of such unit species would not appear from the economic standpoint to be of primary importance. In such crops some sort of group-breeding would appear to be the more practical and easier method of effecting improvement.

IV. Review of past Work.

Some excellent papers have appeared in Europe on the subject of fertility in the genus *Brassica*, but as *toria* and *sarson* do not form the commercial crops of Europe and as it is known that in this genus of plants there is a wide variation in fertility from species to species or even between varieties within one and the same species, these papers do not exactly bear on the subject matter of this publication.

In India itself, where these two crops are commercially important, little work appears to have been done on the study of modes of pollination obtaining in them. The only reference available consists of some preliminary investigations conducted by Howard, Howard, and Abdur Rahman Khan [1910]. These authors say that "*sarson* readily sets seed under bag and a certain amount of self-fertilization is therefore to be expected in free-flowering plants". In *toria*, they say, setting under bag is not so easy as in *rai* (*Brassica juncea*) and *sarson*.

V. Observations and Results.

(A) *Toria*.

Pollination and the floral characters affecting it. Examination of flowers shows that in the bud stage immature stamens are below the stigma with their pollen-liberating sides directed towards the style. As the flower opens, the filaments of the four long stamens increase in length and carry the anthers above the stigma. At the same time these anthers turn half round so that their dehiscing surfaces are turned away from the stigma. This naturally eliminates the chances for the occurrence of self-pollination. The remaining two short stamens, however, continue to have their sutural sides towards the stigma even after the flower has opened; but their anthers remain much below the stigmatic surface. The mechanism is therefore not greatly in favour of self-pollination. Each flower has four nectaries. Nectar is profusely secreted by each of the two nectaries situated at the bases of the two short stamens. The other two nectaries situated at the bases of the pairs of long stamens do not appear to be functional.

The flowers usually open between 8-30 and 10-30 A.M., and as the flowers open the anthers also begin to dehisce from the apex downwards. The dehiscence is usually complete by 12 noon. The flower remains fully open for a day and then it gradually begins to wither and on the fourth or fifth day after opening the sepals, petals, and stamens are shed off. By this time the fertilized ovary also increases in length.

Part played by insects in pollination. As already pointed out above, the floral mechanism in *toria* is such as to reduce the chances for self-pollination to the minimum and therefore the flowers must depend on some external agency for bringing about pollination. Observations made in this connection show that insects play a great part in the pollination and that wind hardly plays any role, if at all, in this respect. The insects start visiting the flowers at 10 A.M. and are met with in largest numbers between 12 noon and 2 P.M. After 3 P.M. their number decreases considerably, so much so that after 4 P.M. hardly any insect can be seen visiting the flowers. For the collection of nectar, which is secreted by the nectaries on that day only on which the flower opens, the insects visit only the freshly opened flowers. It is interesting to note that an examination of the anthers of freshly opened flowers at about 3 P.M. shows them to be absolutely devoid of their pollen grains which are

evidently carried away by the insect visitors. Thirteen kinds of insects have been found visiting *toria* flowers. A preliminary examination of them kindly made for us by the Entomologist to Government, Punjab, shows that most of them belong to the natural order Hymenoptera. These have also been examined by him with a view to discover which parts of the body in the several cases are concerned in carrying the pollen grains. This enables us to gauge the activity of a particular insect as a pollinating agent. The information supplied by the Entomologist is given below in Table II.

TABLE II.

Insects visiting toria flowers and the various parts of their bodies found besmeared with pollen.

Serial No.	Natural order, etc., of the insect.	Parts of the body on which pollen is carried.
1	Hymenoptera . .	Nearly whole body covered including wings. *Legs.*—Third pair and ventral parts of the body more thickly covered over.
2	Hymenoptera . .	*Head.*—Ocellar portion.
3	Hymenoptera . .	*Head.*—Front and ocellar portion. *Thorax.*—Pleural, dorsal and ventral portions more thickly covered over. *Abdomen.*—Ventral portion more thickly covered over than upper part.
4	Hymenoptera . .	*Head.*—Clypeus, ocellar portion and front. *Thorax.*—First two segments more thickly covered over.
5	Hymenoptera . . (Ceratina viridissma).	*Legs.*—Tarsus of second and third pair of legs. *Abdomen.*—Ventral side of last segment.
6	Hymenoptera . .	*Head.*—Front, clypeus, antennæ. *Thorax.*—Prothorax-pleural sides ventral and dorsal sides. *Legs.*—Tibiæ of first and second pair only.
7	Hymenoptera . .	*Head-front, clypeus-thorax.*—Dorsal (prothorax shield) and ventral portion-first segment. *Legs.*—Femur, tibiæ tarsus of second and third pair. *Abdomen.*—Tip of abdomen and first segment ventral portion only.
8	Hymenoptera (Apidæ) .	*Head.*—Ocellar portion, clypeus, front. *Thorax.*—Dorsal side sparsely and ventral portion all covered over. *Legs.*—2nd and 3rd thickly covered over. *Abdomen.*—Ventral portion covered over.
9	Hymenoptera . .	*Head.*—Ocellar bristles. *Thorax.*—Dorsal, only bristles of prothorax. Pollen grains in small numbers only. *Legs.*—All the parts thinly covered over. Tibiæ and tarsus had more pollen grains.
10	Hymenoptera . . (Winged black ant)	*Head.*—Tip of mouth parts. *Thorax.*—Prothoracic portion only. *Legs.*—First pair only. *Abdomen.*—Tip of the abodmen.
11	Lepidoptera . . (Danais butterfly).	*Head.*—Only tip of the tongue.
12	Lepidoptera . . (Junonia crithya)	Only tip of the tongue slightly covered over. No other part of the body had a single grain of pollen.
13	Diptera (House. fly) .	No pollen.

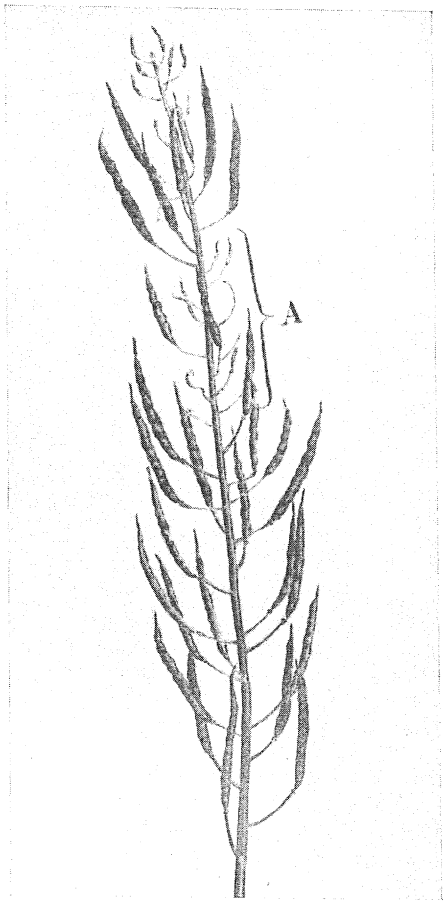

Fig. 1. Branch of a *toria* plant showing podless gaps (A) brought about by the intervention of cloudy, humid, rainy weather during flowering.

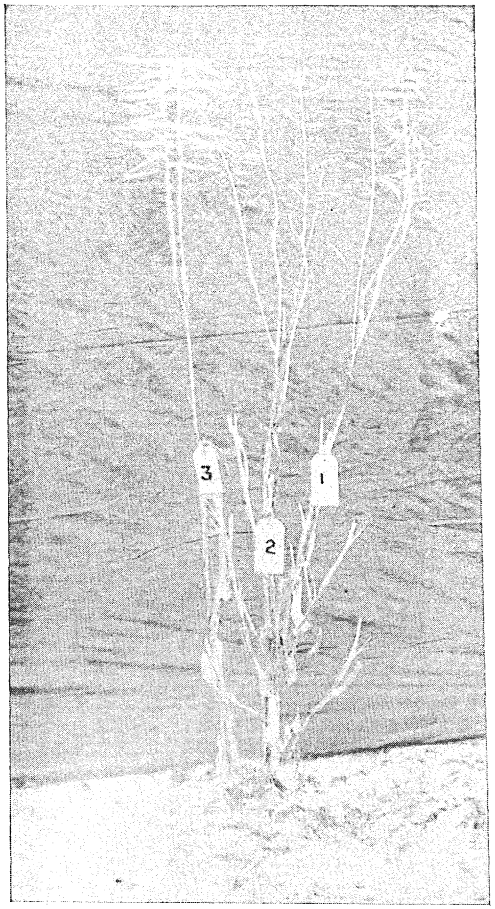

Fig. 2. A *toria* plant showing fruit formation under three treatments — 1, selfed by hand ; 2, bagged only ; 3, crossed.

Besides these insects, Thrips have also been met with in *toria* flowers. But the part they play in the pollination has yet to be ascertained; investigations on this point are in progress.

Detailed observations were recorded during the year 1929-30 with regard to the frequency of insect visits to flowers. For this purpose, a number of individual flowers and also inflorescences were earmarked at different places in a field and the number of insects visiting them per hour was recorded for about a fortnight from 9 A.M. to 5 P.M. daily. The results show that, on the average, an inflorescence and a flower were visited by insects 71 and 26 times respectively per day. The frequency of insect visits is so great that there is absolutely no chance for a flower to escape pollination through the agency of insects. It may, however, be pointed out that the activity of insects is largely controlled by weather. It has been definitely ascertained that very few insects come out to visit flowers on cloudy days and, even if some insects do come out at all, they remain lethargic. A comparison of the number of hourly visits by insects to an individual inflorescence on a cloudy and a clear day is given in Table III below:—

TABLE III.

Comparison of the frequency of insect visits on a cloudy and a clear day.

Kind of Weather	Number of insect visitors between.								
	9 and 10 A.M.	10 and 11 A.M.	11 and 12 A.M.	12 A.M. and 1 P.M.	1 and 2 P.M.	2 and 3 P.M.	3 and 4 P.M.	4 and 5 P.M.	Total
Clear day .	..	13	20	29	42	28	21	..	153
Cloudy day .	..	..	1	..	..	2	..	..	3

It is apparent from the above that the number of insects visiting the flowers on a clear day is far greater than those visiting the flowers on a cloudy day. Naturally, therefore, whatever setting occurs on cloudy days takes place from natural self-pollination, whose extent in this crop, as will be shown later, is very little.

Weather as affecting pollination and yield. From the above facts it follows that the intervention, during the blossoming period of *toria*, of long spells of weather containing cloudy, humid, or rainy elements would decrease the percentage of setting. It has actually been observed that the flowers opening on a cloudy, humid day do not set into pods, with the result that, if such weather lasts sufficiently long, considerable podless gaps appear on the fruiting branches (Plate XIV, fig. 1) and the yield is considerably reduced. Average yields of *toria* crop at the Lyallpur Agricultural Farm worked out for the years 1925-26 to 1929-30 and the experience of farmers round about Lyallpur considered along with the number of cloudy days, humidity, and rainfall during November months (when most of the flowering and

pod-setting takes place in *toria*) of these years, seem to confirm this observation. Average yields of *toria* obtained at the Lyallpur Agricultural Farm (in no case from less than 15 acres) with weather data are as follows, with humidity shown in Fig 1.

Year	No. of cloudy days in November	No. of rainy days in November	Total rainfall in inches in November	Average yield per acre
				Mds. sr. ch.
1925-26	14	3	0·54	9 27 0
1926-27	7	..	..	10 32 0
1927-28	7	..	..	10 9 0
1928-29	16	4	2·14	7 22 0
1929-30	11	..	..	12 34 0

Further details of weather data are given in statements appended at the end.

From the above it will be seen that, of the years under consideration, the years 1928-29 and 1925-26 which gave the lowest yields had in November the greatest rainfall, and the largest number of rainy and cloudy days. Of these two years, humidity data are available for 1928-29 only (Fig. 1) and it will be seen that the humidity for the November of this year is the highest of all the remaining years. On the other hand, November months of the remaining three years which yielded decidedly better than the first mentioned two years had the least of these adverse climatic factors. Of the latter years, the cloudiness of 1929-30 is decidedly over-represented by the actual figures of cloudy days given, as from personal observations made by the authors it is known that whenever there were any clouds during November of this year they generally disappeared each day about noon, with the result that though the daily visits of insects were delayed yet the pollination was not intrefered with as the insects came in larger numbers in the afternoons.

It is not possible to say definitely whether the reduction in setting owing to the intervention of cloudy, humid, rainy weather is entirely due to the consequent reduction in the visits of pollinating insects or to the increased humidity of the atmosphere also, as the experiments of crossing flowers was not carried out on such days. It has been ascertained, however, that, unlike cotton pollen, *toria* pollen grains do not burst on coming into contact with free water. From this it appears likely that the above mentioned reduction in setting is simply the result of reduction in the visits of pollinating insects.

The weather in the period immediately following setting, that is in the month of December, is also of importance in so far as the development of pods is concerned. Demand for food materials required for filling up the pods is greatest at this time, and the prevalence, at this stage, of unfavourable conditions such as drought and deficiency of soil moisture is sure to reduce the yield by cutting down food supplies and by increasing the liability of the crop to suffer from early frost. It is interesting to note in this connection that the season in this respect has been most favourable during the year 1929-30. This fact, coupled with the favourable conditions prevalent during the month of November of this year, seems to be responsible for the highest yield obtained this year. The number of rainy days and the total amount of

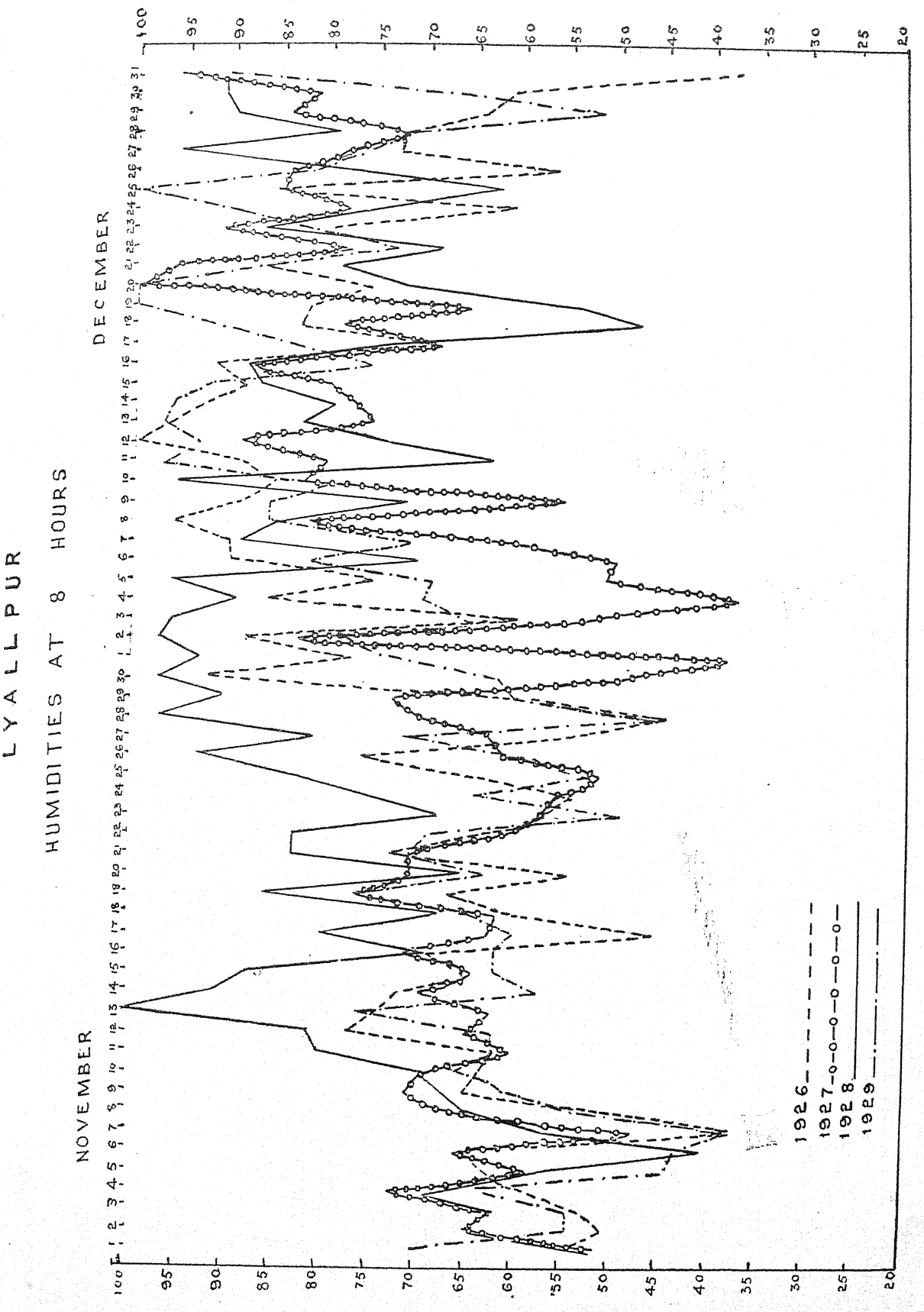

Fig. 1. Humidities at Lyallpur for the four years ending 1929-30.

rainfall during the month of December in the five years under consideration were as follows :—

Year	December	
	No. of rainy days	Total rainfall in inches
1925-26	*Nil*	*Nil*
1926-27	2	0·06
1927-28	2	0·43
1928-29	1	0·04
1929-30	5	0·72

From the foregoing it appears that the yield in *toria* is largely determined by weather conditions obtaining during the months of November and December. Apparently other things being equal, clear sunny weather from about the end of October to about the end of November and a moderately humid season and a good water supply during December are ideal conditions for obtaining high yields in this crop.

(B) *Sarson.*

Pollination and the factors concerned. The floral mechanism in all brown-seeded forms of *sarson* that have been under observation so far is the same as in *toria* so that the chances for natural self-fertilization are few. But one form of *sarson*, which is yellow-seeded and is commonly grown towards Rawalpindi side, has been found to differ in this respect. In this case, the pollen-liberating sides of the anthers of the long stamens remain towards the stigma even in a fully opened flower. These anthers at the time of dehiscence meet over the stigma and then begin to turn away from the stigmatic surface, each forming a sort of coil. A little-before, or during this process, some pollen drops on the stigma so that a certain amount of self-fertilization is to be expected. The anthers of the short stamens do not, however, reach the stigma and therefore do not appear to take any part in this self-pollination. As regards mode of pollination, all *sarsons*, with the exception of this particular form, have been found to behave in almost the same manner as *toria*. About 26 different kinds of insects were found to visit *sarson* flowers in the year 1929-30. A collection of these is under study, and experiments have been started to discover the part played in pollination by each insect. The results will be given out in a separate note. The fact, however, stands that insect visit is essential to obtain satisfactory setting in *sarson* as is the case in *toria*.

VI. Self and cross-fertilization in Toria and Sarson.

In order to explore the possibilities of isolation of pure lines in *toria* and *sarson*, attempts were made to secure self-fertilized seed of them by enclosing plants in muslin bags. It was repeatedly observed that in these two crops, excepting in one form of *sarson*, which is yellow-seeded, little setting results and consequently a sufficient supply of seed from single plants cannot be obtained. Percentage of

setting under bag was determined in each of the years 1926-27 to 1929-30, inclusive, and the figures obtained are given in Table IV below :—

TABLE IV.

Results of setting under bag in Toria and Sarson for the years 1926-27 to 1929-30.

Year	TORIA			SARSON					
				BROWN-SEEDED FORMS			YELLOW-SEEDED FORM		
	No. of flowers bagged	No. of pods set	Percentage of setting	No. of flowers bagged	No. of pods set	Percentage of setting	No. of flowers bagged	No. of pods set	Percentage of setting
1926-27 .	3,328	282	8·4	10,855	1,773	16·3	38	38	100
1927-28 .	7,357	1,147	15·5	606	185	30·5	162	135	83·3
1928-29 .	8,052	677	8·4	1,137	263	23·1	..	..	..
1929-30 .	1,019	277	27·1	3,614	1,047	28·9	..	..	..
TOTAL (or average).	19,756	2,383	12·1	16,212	3,268	20·1	200	173	86·5

From the figures in Table IV it will be seen that on the average of four years there is a pod-setting under bag of 12·1 per cent. and 20·1 per cent. respectively in *toria* and brown-seeded *sarsons*. It may be pointed out, however, that the actual setting is very much less than this because the pods, which succeed in setting inside bags, contain only a fraction of the number of seeds which pods formed by free-flowering plants do. As will be seen from Tables given later on, in *toria* and *sarson* for every one normal seed formed inside bag, about 40 and 27 seeds respectively are formed outside on free-flowering branches.

It is possible that some of the very small, poor, and shrivelled seeds obtained from selfing, if made to germinate under suitable conditions and specially nursed, may give rise to haploid plants as Jørgensen [1928] found to be the case in the genus *Solanum*.

With a view to determine whether the very poor setting obtained under bag was entirely due to the floral mechanism providing few chances for pollination or to some other cause also, and also to find out if with the aid of artificial self-pollination self-fertilized seed from individual plants could be had in quantities sufficient to permit of the isolation of pure lines, certain experiments were carried out on a

number of *toria* plants in the year 1927-28. In each case, on one and the same plant different branches were accorded one of the three treatments. One branch was left free-flowering, *i.e.*, open to the visits of insects; a second one was bagged but otherwise left untouched; while the third was bagged but flowers on it were each day self-pollinated by a camel's hair brush. The results so obtained are given in Table V, from which it will be seen that on the average, for every 100 flowers treated, artificial selfing by means of hand-pollination increased the amounts of both pod-setting and seed production from 14·5 and 27 to 33·6 and 90 respectively. But this result remains far short of that (*i.e.*, 66 pods and 1,086 seeds formed per 100 flowers) obtained from free-flowering branches, left open to the visits of insects. It will also be seen that, while artificial selfing appreciably increased pod-setting, seed production per pod it increased very little. This shows that pod-formation and seed-formation in *toria* were in these experiments largely independent. Such was found to be the case by Nelson [1927] in some selfing experiments with some other forms of the genus *Brassica*.

In these experiments some damage occurred to flowers due to handling or some other cause and such damaged flowers have been included in the above figures in the class of failures. Taking this damage out of account, production of normal seeds was as follows :—

Every 100 bagged flowers gave on the average 40 normal seeds.

Every 100 bagged but artificially selfed flowers gave on the average 186 normal seeds.

Every 100 unbagged flowers open to the visits of insects gave on the average 1,269 seeds.

These figures, though slightly different, are of the same order as previous ones and lead to the conclusion that in *toria* even self-pollination by hand does not produce an appreciable amount of seed. During the artificial selfing of flowers on any individual plant, the hair brush was not sterilized in going from one flower to another and therefore it is justifiable to conclude that in a good many cases, if not in all practically, pollen grains and stigmas of different flowers must have come into contact. If there is any difference in time of maturity between pollen and stigma of the same flower, this as a cause of self-sterility must be ruled out.

In order to see whether the poor setting under bag, with or without artificial selfing, was in some way due to the effect of bags used for enclosing the branches, experiments were arranged to compare the following three treatments :—

(*a*) Flowers were bagged only.

(*b*) Flowers were artificially selfed by hand under bag.

(*c*) Flowers under bag were crossed with pollen from other *toria* plants.

In each set of these experiments the three different treatments were given to flowering branches on the same plant and the muslin bags used were in all cases of the same and ordinary sort as are used in the Botanical Section, Lyallpur, for bagging *toria* and *sarson* plants. The results obtained are given in Table VI, from

which it will be seen that crossed flowers under bag gave an excellent setting, immensely greater than in the cases where setting depended on selfing alone, natural or artificial. It will also be seen that while artificial selfing appreciably increased pod-setting, it made no increase in the production per pod of normal seeds. Crossing under bag gives not only an immense improvement in setting, but the pods formed are also much bigger and better developed (Plate XIV, fig. 2 and also Table VIII). From Table VIII it will be seen that " selfed " pods have about half the length of those " crossed " and that the loss in length which results from selfing is mainly confined to the seed-bearing portion of the pod.

The foregoing results leave no doubt that bags interfere in no way with fertilization and pod and seed development, and that the *toria* plant is highly self-sterile and only partially self-fertile.

Similar experiments were conducted in 1929-30 on *sarson*, results of which are given in Table VII. It will be seen from this Table that these results are exactly similar to those obtained in the case of *toria*. It will also be seen that even slightly better pod-setting and seed-production were obtained with crossing than in the case of free-flowering branches, which is plausible on the assumption that in the case of free-flowering branches a small number of flowers must have been partly pollinated with their own pollen.

TABLE V.

Comparison of setting in free-flowering, artificially selfed, and naturally selfed flowers in Toria *in the year 1927-28.*

Plant No.	BAGGED						BAGGED BUT ARTIFICIALLY SELFED (HAND-POLLINATED)						FREE-FLOWERING					
	Total No. of flowers under observation	Total No. of pods formed	Percentage of pod-setting	Average No. of normal seeds per pod	Total No. of normal seeds	Average No. of normal seeds calculated per 100 flowers	Total No. of flowers treated	Total No. of pods formed	Percentage of pod-setting	Average No. of normal seeds per pod	Total No. of normal seeds	Average No. of normal seeds calculated per 100 flowers	Total No. of flowers under observation	Total No. of pods formed	Percentage of pod-setting	Average No. of normal seeds per pod	Total No. of normal seeds	No. of normal seeds formed per 100 flowers
1	289	123	42·6	2·62	322	..	41	37	90·2	4·36	161	..	62	50	80·6	22·18	1,109	..
2	679	93	13·7	1·40	130	..	51	36	70·6	2·58	93	..	102	63	61·8	17·90	1,127	..
3	151	23	15·2	1·05	24	..	42	20	47·6	1·10	22	..	42	25	59·5	16·52	413	..
4	222	1	0·4	0·00	0	..	86	6	7·0	0·50	3	..	44	20	45·0	10·15	203	..
5	253	16	6·3	1·37	22	..	32	5	15·6	1·20	6	..	57	40	70·2	11·02	441	..
6	266	24	9·0	1·14	27	..	42	2	4·8	1·00	2	..	85	70	82·3	18·23	1,276	..
7	137	10	7·3	1·70	17	27	30	3	10·0	1·66	5	90	80	45	56·2	12·33	555	1,086
Average .	..	..	14·5	..	..	27	..	..	33·6	..	..	90	..	..	66·0	..	..	1,086

TABLE VI.

Comparison of setting in Toria *under bag in untouched, artificially selfed, and crossed flowers, in the year 1929-30.*

Plant No.	UNTOUCHED						ARTIFICIALLY SELFED (HAND-POLLINATED)						CROSSED					
	Total No. of flowers under observation	Total No. of pods formed	Percentage of pod-setting	Average No. of normal seeds	Total No. of normal seeds	No. of normal seeds formed per 100 flowers	Total No. of flowers treated	Total No. of pods formed	Percentage of pod-setting	Average No. of normal seeds per pod	Total No. of normal seeds	Average No. of normal seeds calculated per 100 flowers	Total No. of flowers treated	Total No. of pods formed	Percentage of pod-setting	Average No. of normal seeds per pod	Total No. of normal seeds	Average No. of normal seeds calculated per 100 flowers
1	85	47	55·3	2·3	107	..	68	54	79·4	2·4	131	..	50	50	100·0	22·3	1,114	..
2	45	11	24·4	1·0	11	..	72	29	40·3	3·1	63	..	30	30	100·0	17·8	534	..
3	52	28	53·8	1·3	36	..	80	41	51·2	1·1	45	..	40	40	100·0	14·3	572	..
4	66	7	10·6	1·4	10	66	22	13	59·1	1·4	18	106	20	20	100·0	19·4	388	1,863
Average .	..	..	37·5	..	..	66	..	..	56·6	..	..	106	..	..	100·0	..	..	1,863

TABLE VII.

Comparison of setting in Sarson, *of untouched, artificially selfed and crossed flowers under bag and flowers left unbagged, in the year 1929-30.*

Plant No.	BAGGED ONLY (OTHERWISE UNTOUCHED)						BAGGED AND ARTIFICIALLY SELFED (HAND-POLLINATED						FREE-FLOWERING						BAGGED AND CROSSED					
	Total No. of flowers treated	Total No. of pods formed	Percentage of pod-setting	Average No. of normal seeds per pod	Total No. of normal seeds	No. of normal seeds calculated per 100 flowers	Total No. of flowers treated	Total No. of pods formed	Percentage of pod-setting	Average No. of normal seeds per pod	Total No. of normal seeds	Average No. of normal seeds calculated per 100 flowers	Total No. of flowers treated	Total No. of pods formed	Percentage of pod-setting	Average No. of normal seeds per pod	Total No. of normal seeds	Average No. of normal seeds calculated per 100 flowers	Total No. of flowers treated	Total No. of pods formed	Percentage of pod-setting	Average No. of normal seeds per pod	Total No. of normal seeds	Average No. of normal seeds calculated per 100 flowers
1	25	8	32·0	1·4	11	..	25	10	40·0	2·9	29	..	22	18	81·8	14·8	266	..	27	27	100·0	14·2	384	..
2			Branches						Damaged				10	10	100·0	11·6	116	..	11	11	100·0	13·3	146	..
3	80	17	21·2	1·5	25	..	8	3	37·5	1·3	4	..	20	19	95·0	15·8	300	..	25	25	100·0	20·8	521	..
4	37	7	18·9	2·8	20	..	26	10	38·6	2·8	28	..	16	15	93·7	21·3	319	..	26	26	100·0	19·4	504	..
5	84	33	39·3	2·4	80	60	30	19	63·3	3·7	44	118	10	10	100·0	24·4	244	1,596	17	17	100·0	24·3	411	1,855
Average	..	..	29	..	..	60	..	..	47	..	..	118	..	..	92	..	..	1,596	..	..	100·0	..	..	1,855

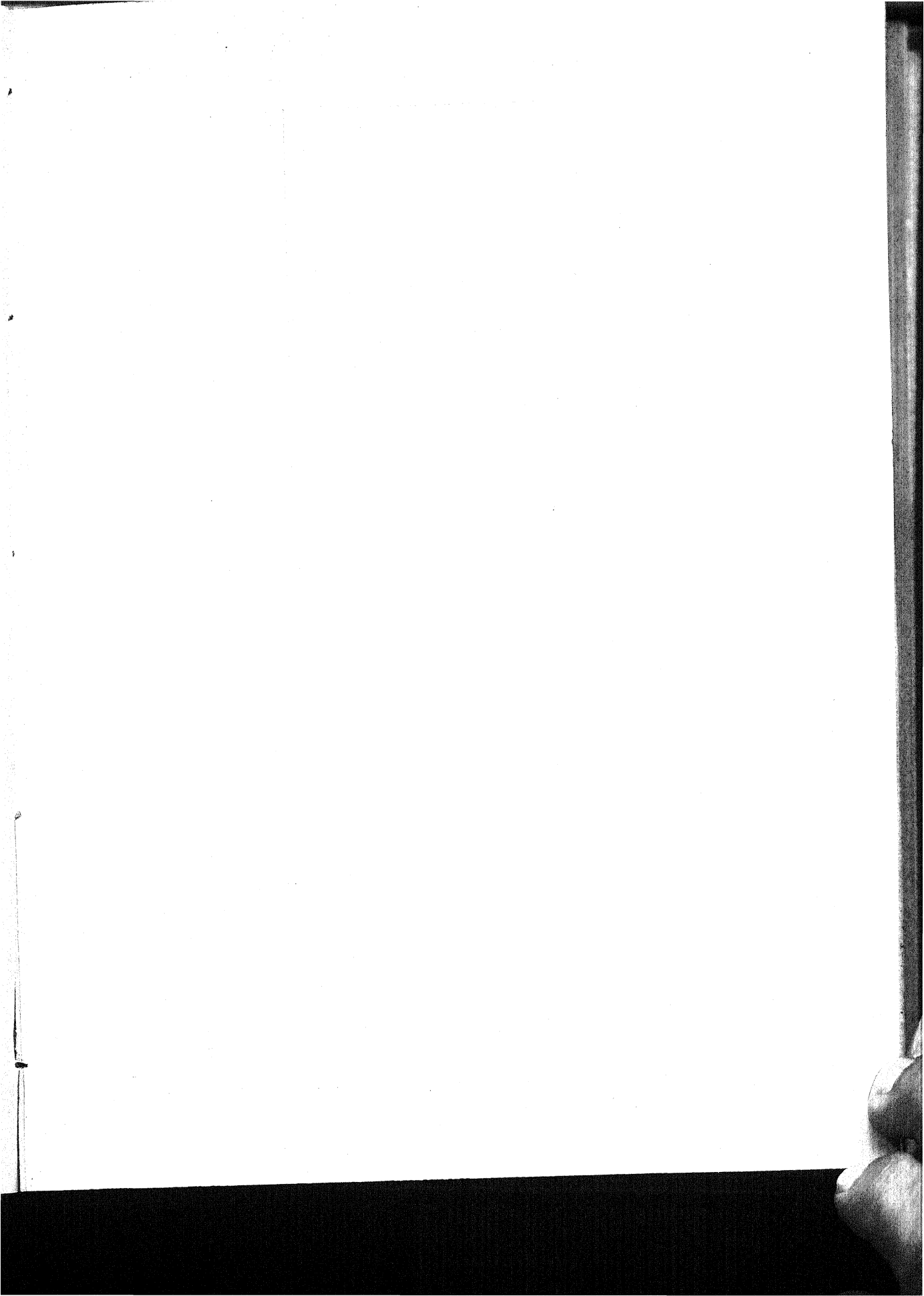

PLATE XV.

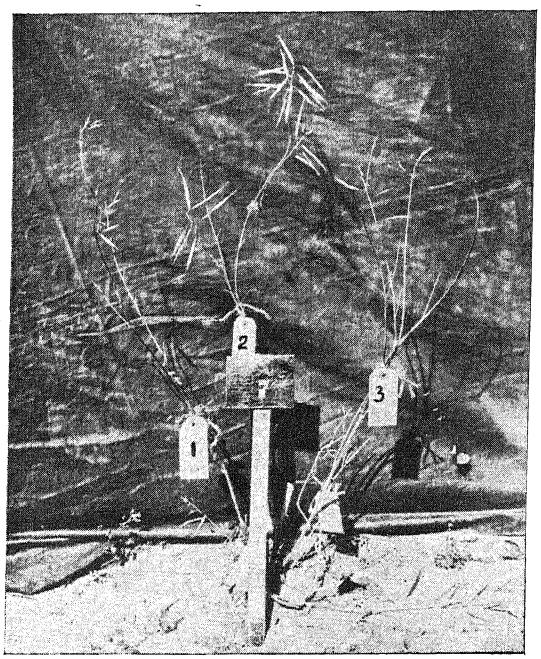

Fig. 1. A *sarson* plant showing fruit formation under three treatments — 1, selfed by hand; 2, crossed; 3, bagged only.

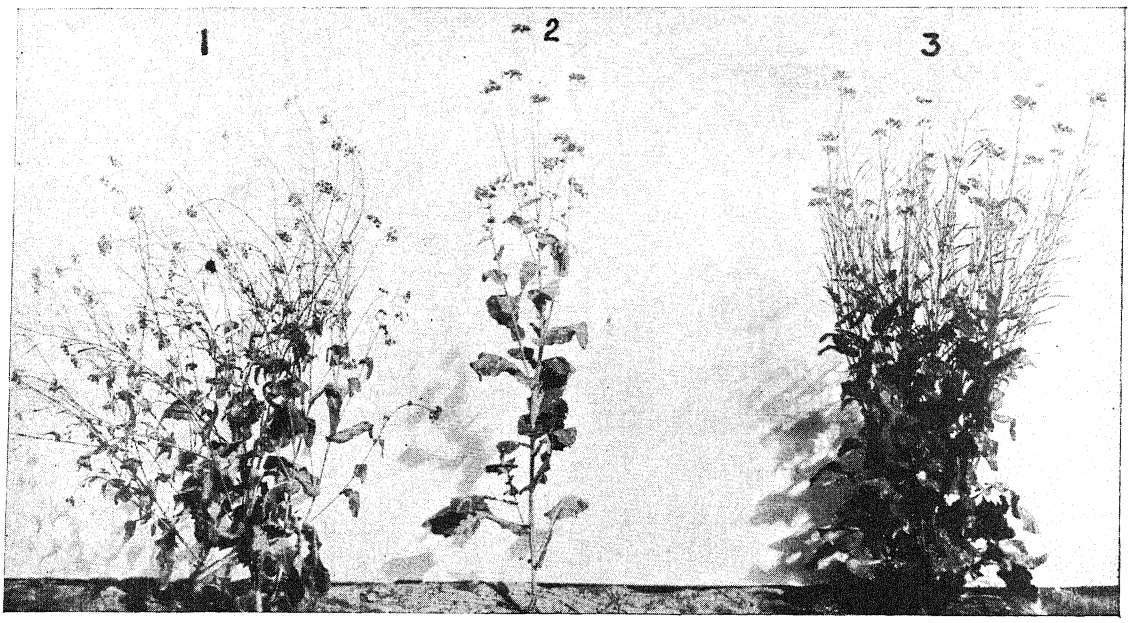

Fig. 2. *Toria* plants with different habits — 1, a straggling, open plant; 2, a very sparsely branched plant; 3, an ideal plant with numerous ascending branches.

In brown-seeded *sarsons* also, as in the case of *toria*, pods formed as a result of crossing are much bigger (Plate XV, fig. 1) and contain incomparably greater number of seeds than the pods produced by natural or artificial selfing. Results of experiments bearing on these points, both for *toria* and *sarson*, are tabulated in Table VIII, which figures show that in by far the most of the cases natural or artificial selfing in *toria* and brown-seeded *sarsons* reduces the length of the pods to $\frac{2}{3}$-$\frac{1}{2}$ of that given by " crossed " flowers and the number of seeds to $\frac{1}{6}$-$\frac{1}{12}$. As already stated, the loss in length of pod which so takes place is mainly confined to its seed-bearing portion, affects the beak very slightly, and has practically no effect on the pedicel.

From Table VIII it will also be seen that very little reduction of this sort takes place in the yellow-seeded form of *sarson*. As already shown in Table III above, this particular form of *sarson*, unlike brown-seeded forms, gives an exceptionally good setting under bag due to the floral mechanism affording facilities for self-pollination. As shown in the case of *toria* and brown-seeded forms of *sarson*, presence, however, of facilities enabling self-pollination is not enough. The plant must have the quality of self-compatibility, which quality the yellow-seeded form of *sarson* seems actually to possess.

VII. Loss of vigour on inbreeding.

From the foregoing state of affairs, it is naturally to be expected that inbreeding (self-fertilization) in these two plants would lead to loss of vigour. This has actually been observed in the field to be the case with *sarson*. Material for this was provided in the year 1928-29 by eight pairs of lines, each pair of which had one line from bagged (selfed) seed and the other adjacent one from unbagged (more or less crossed) seed, from one and the same plant of brown-seeded *sarson* of previous years. In seven cases out of the eight observed, progeny of unbagged seed was much more vigorous than the progeny of the seed from the bagged (*i.e.*, selfed) portion of the plant. No opportunity has so far offered itself to obtain such direct evidence in the case of *toria* owing to the fact that very little viable seed of it is obtained under bag. But if such is the case with *sarson*, wherein setting under bag is better than in *toria*, so must be the case with *toria* itself.

VIII. Breeding improved varieties.

In the light of above it will be seen that, in *toria* and brown-seeded *sarson*, pure lines, though they can be produced by continued (enforced) inbreeding, have as such no utility for the farmer. Crossing in these two crops is a sure means of obtaining high yields, which in the breeding of improved varieties should not there-

fore be excluded. What is required is not to exclude crossing altogether, but to limit it within certain desirable forms. In the case of *toria*, such desirable or choice plants should for various reasons possess the following attributes. (For other

TABLE VIII.

Reduction which takes place, on selfing, in Toria *and* Sarson *in the length of pods and number of normal seeds.*

Crop	Year	Treatment	No. of flowers treated	Average length in centimeters, per pod				Average No. of normal seeds per pod
				Entire pod	Pedicel	Seed bearing portion	Beak	
Toria . .	1927-28	Bagged . .	1,997	4·46	1·42	2·05	0·99	1·33
		Free-flowering .	472	6·84	1·53	3·95	1·36	15·48
	1929-30	Bagged . .	248	4·77	1·67	2·17	0·93	1·50
		Hand-selfed .	242	5·15	1·72	2·40	1·03	2·00
		Crossed . .	140	8·95	1·77	5·42	1·76	18·45
Sarson brown-seeded.	1927-28	Bagged . .	606	5·30	1·50	2·40	1·40	1·86
		Free-flowering .	145	6·60	1·60	3·60	1·40	6·18
	1929-30	Bagged . .	226	4·72	1·75	2·25	0·72	2·02
		Hand-selfed .	89	5·02	1·60	2·47	0·93	2·67
		Free-flowering .	68	7·70	1·95	4·35	1·40	19·07
		Crossed . .	95	8·10	1·75	4·90	1·45	19·67
Sarson yellow-seeded.	1927-28	Bagged . .	104	7·10	1·50	4·10	1·50	14·01
		Free-flowering .	91	7·10	1·60	4·30	1·20	17·11

details *see* " Points for seed-selection in *toria* " by author No. 2 in the *Seasonal Notes of the Punjab Agricultural Department*, Vol. VI, 1929.)

1. Habit should be profusely branching, with branches ascending so that the form of the plant should be more or less like that of an inverted club or cone. Plants having wide, open tops or no branches should be discarded. The former occupy too much space for the yield they give. Plate XV, fig. 2, shows plants with these different types of habit, in which No. 3 has got the ideal habit and Nos. 1 and 2 represent the types of plant which should be discarded.

2. Plants selected should be mediumly early so that growth and development of the crop may be completed by the time the season gets too cold and frosty. They should also be of uniform maturity, absence of which causes harvesting troubles.

3. They should be profusely podded or have the capacity to do so.

4. The seeds should be bold as bolder seeds contain a higher percentage of oil than small ones.

Varieties derived from group-breeding cannot but be "mass" varieties, which are liable to change when introduced into new localities with different environments. It is therefore essential that in any particular tract the breeding should be done in several places representative of all its regions. Nature herself acts as guide in this respect. Grow identical mixtures of forms in two widely differing places for a number of years, when it will be found that each locality has evolved a type of its own. Such types have been called ecotypes, and it is actually the case that every region has its own ecotypes of crops like *toria* and *sarson*. They are not types in the sense of pure lines, but possess in many outward characters a sort of uniformity as to give an impression to the lay observer that the individual members of such a group are quite identical.

IX. Some Correlations.

It has already been pointed out that the yellow-seeded form of *sarson* gives very good setting under bag, which means that in *sarson* there is close association between self-fertility and yellowness of colour of seeds. Another useful correlation having a commercial utility was discovered both in *toria* and brown-seeded forms of *sarson*, namely, that red or reddish seeds weigh less than the black or blackish seeds. A comparison of the two kinds of seed is given in Table IX, from which it will be seen that, on the average of a number of determinations made, 100 black or blackish seeds weigh 21 per cent. and 35 per cent. higher in *toria* and *sarson* respectively than the red or reddish seeds. This is in accordance with what Sirks [1926] found to be the case. This difference is probably due to differences in nutrition as it has been found that both in *toria* and *sarson* black or blackish seeds predominate in the basal portions of the branches. This predominance is in the case of *toria* reversed, however, by the middle of a branch, and further on, the predominance of red or reddish seeds becomes greater and greater until at the tip there

TABLE IX.

Comparing the weight of black and red seeds in Toria *and* Sarson, *Lyallpur Botanical Area, 1927-28.*

Plant No.	*TORIA*			*SARSON*		
	WEIGHT IN GRM. PER 100 SEEDS			WEIGHT IN GRM. PER 100 SEEDS		
	Black	Red	Difference in favour of black seeds	Black	Red	Difference in favour of black seeds
1 . . .	0·340	0·262	0·078	0·567	0·378	0·189
2 . . .	0·347	0·330	0·017	0·471	0·352	0·119
3 . . .	0·445	0·365	0·080	0·366	0·295	0·071
4 . . .	0·331	0·215	0·116	0·357	0·295	0·062
5 . . .	0·355	0·310	0·045	0·416	0·301	0·115
6 . . .	0·370	0·265	0·105	0·427	0·332	0·095
7 . . .	0·351	0·317	0·034	0·397	0·269	0·128
8 . . .	0·330	0·295	0·035	0·414	0·295	0·119
9 . . .	0·367	0·315	0·052	0·383	0·299	0·084
Average . .	0·359	0·297	0·062	0·422	0·313	0·109
(In terms of 100)	121	100	21	135	100	35

are about 3 of them to 1 of black or blackish sort. But, in *sarson*, it goes a long way up and it is only at the tip that it suffers a diminution.

X. INTER-CROSSING AMONG SOME OF THE BRASSICAE.

A number of inter-crosses were attempted between *toria* and *sarson*, and between them and some other Brassicae, as follows :—

1. *Sarson* ♀ × *Toria* ♂
2. *Sarson* ♀ × Turnip ♂
3. *Sarson* ♂ × Turnip ♀
4. *Sarson* ♂ × Mustard ♀
5. *Toria* ♀ × Turnip ♂
6. *Toria* ♂ × Turnip ♀

TABLE X.

Results of inter-crossing among some of the Brassicae, in 1929-30.

Cross	Seed parent	Treatment	Total No. of flowers treated	No. of pods formed	Per cent. pod setting	Average length in cm. per pod				No. of normal seeds per pod
						Entire pod	Pedicel	Seed bearing portion	Beak	
1. Sarson × Toria	Sarson	Crossed	25	24	96·0	9·9	2·1	6·0	1·8	19·3
		Free-flowering	10	10	100·0	9·7	2·2	5·6	1·9	26·8
2. Sarson × Toria	Sarson	Crossed	22	22	100·0	8·4	1·6	5·1	1·7	18·5
		Free-flowering	10	10	100·0	8·1	1·8	4·6	1·7	14·8
3. Japan sarson (White leaved) × Toria.	Sarson	Crossed	25	25	100·0	8·8	2·3	4·7	1·8	16·0
		Free-flowering	10	10	100·0	10·1	3·3	4·8	2·0	20·1
4. Sarson × Turnip	Sarson	Crossed	30	30	100·0	9·2	2·0	5·4	1·8	21·5
		Free-flowering	10	10	100·0	9·3	2·6	5·0	1·7	22·2
5. Sarson × Turnip	Turnip	Crossed	30	30	100·0	7·8	1·5	4·4	1·9	15·3
		Free-flowering	10	10	100·0	7·2	1·4	4·4	1·4	18·2
6. Sarson × Mustard	Mustard	Crossed	25	25	100·0	5·7	1·6	3·1	1·0	8·0
		Free-flowering	10	10	100·0	5·6	1·4	3·3	0·9	11·5
7. Toria × Turnip	Toria	Crossed	20	20	100·0	9·7	1·5	5·6	2·6	16·5
		Free-flowering	10	10	100·0	10·1	3·1	4·5	2·5	12·8
8. Toria × Turnip	Turnip	Crossed	25	25	100·0	8·0	1·3	4·8	1·9	23·4
		Free-flowering	10	10	100·0	7·2	1·4	4·4	1·4	18·2

Results of these inter-crosses are given in Table X, from which it will be seen that *sarson* crosses readily with *toria*, turnip, and mustard, and that *toria* crosses readily with *sarson* and turnip. Pods and seeds formed as a result of these crosses are quite normal as compared with pods and seeds formed on the free-flowering branches of the seed parent in each case. F_1 generations of these crosses have yet to be grown and studied further and therefore no comment on them is at this stage attempted.

Inter-crossing was also attempted in both directions between *sarson* and *taramira* (*Eruca Sativa*), the latter an *ex*-Brassica oil-seed plant but belonging to the common family Cruciferae. With *taramira* as the mother plant, not a single flower out of the 15 crossed formed any pod. With *sarson* as the mother plant, however, two out of the 15 flowers crossed did form pods, but these pods were only about half the length of the normal *sarson* pods and each of them contained only one normal seed, instead of about 12 met with on sister free-flowering branches. It remains to be determined whether these two seeds were the result of accidental selfing at the time of emasculation or are really due to the interaction of the pollen of the one with the stigma of the other. Further investigations on these and many other similar problems are being continued by authors Nos. 1 and 3.

XI. Summary.

1. *Toria* and *sarson*, for which the botanical names *Brassica napus* L. var. *dichotoma* Prain, and *Brassica Campestris* L. var. *Sarson* Prain, have been used in this publication on the authority of Prain, are by far the most important oil-seed plants of the Punjab.

2. In both of them, the floral mechanism is such that it provides few chances for natural selfing. Under bags they are shy seed-setters. On an average of four years, only 12·1 and 20·1 per cent., respectively, of *toria* and *sarson* flowers formed pods under such conditions and many of these pods were pods in name only, with their seed-bearing portions greatly reduced. They contain very few normal seeds. Production of normal seeds themselves under bag is about $\frac{1}{40}$th and $\frac{1}{27}$th, respectively, of that in free-flowering branches open to the visits of insects.

3. The yellow-seeded form of *sarson* is an exception to this. It gives quite good setting under bag.

4. Artificially selfing them (*toria* and brown-seeded *sarson*) by hand-pollination, though it hardly increases the number of normal seeds per pod, makes some increase in the number of pods set. This increased production remains far short, however, of that on the free-flowering branches open to the visits of insects.

5. From crossing under bag and getting even a better setting than on free-flowering branches, combined with the fact that artificial selfing does not improve matters much, it is concluded that the high amount of self-sterility prevailing in these two plants is not due to external causes alone, but due to internal ones (self-incompatibility) also.

6. Yields of *toria* are adversely affected if there occur in November long spells of cloudy, humid, rainy weather. This is due to the fact that insects do not come out on such days to pollinate the flowers.

7. With the lack of selfing facilities and large degree of self-sterility prevailing in these two plants, it was to be expected that in-breeding (strict self-fertilization) would lead to loss of vigour. Direct evidence has been obtained for this in the case of *sarson* and so, no doubt, must be the case with *toria*.

8. In view of loss of vigour in these crops from in-breeding, pure lines as such have no direct economic utility. To obtain improved varieties, some sort of group-breeding must be resorted to. Points for selection have been mentioned.

9. In both *toria* and *sarson*, red-coloured seeds weigh less than black-coloured ones.

10. *Sarson* crosses readily with *toria*, turnip and mustard (all, different species of the genus *Brassica*) and *toria* crosses readily with *sarson* and turnip. In the latter case a cross with mustard was not attempted.

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Appendix I.

Statement showing the number of cloudy days, cloud amount and the rainfall in inches at Lyallpur for the months of November and December during the year 1925-26.

Date	November		December	
	Cloud amount	Rainfall in inches	Cloud amount	Rainfall in inches
1	8	..	..	..
2	2	..	..	..
3	10	..	..	..
4	10	0·05	4	..
5	10	0·13	..	..
6	10	..	..	..
7	10	0·36	..	..
8	..	..	10	
9	..	..	2	..
10	..	..	..	..
11	..	..	..	..
12	..	..	1	
13	..	..	..	..
14	7	..	4	..
15	..	..	..	..
16	..	..	..	..
17	2	..	..	..
18	..	..	..	..
19	..	..	..	..
20	..	..	..	..
21	3	..	..	..
22	10	..	10	..
23	..	..	10	..
24	8	..	10	..
25	2	..	10	..
26	..	..	..	..
27	..	..	2	..
28	6	..	..	..
29	..	..	..	..
30	..	..	..	..
31	..	..	..	..
Total — No. of cloudy days	14	..	10	..
Total — No. of rainy days	..	3	..	*Nil*
Total — Rainfall in inches	..	0·54	..	*Nil*

APPENDIX II.

Statement showing the number of cloudy days, cloud amount and the rainfall in inches at Lyallpur for the months of November and December during the year 1926-27.

Date	NOVEMBER		DECEMBER	
	Cloud amount	Rainfall in inches	Cloud amount	Rainfall in inches
1	..	..	8	..
2	..	..	8	..
3	..	..	10	..
4	..	..	10	..
5	..	..	3	..
6	2	..	10	..
7	..	..	3	..
8	2	..	10	..
9	..	..	..	..
10	10	..	..	..
11	10	..	10	0·01
12	..	..	..	..
13	..	..	3	..
14	..	..	10	0·05
15	..	..	..	..
16	..	..	..	..
17	..	..	..	..
18	6	..	10	..
19	..	..	..	..
20	2	..	..	..
21	..	..	2	..
22	..	..	..	..
23	..	..	..	..
24	..	..	10	..
25	..	..	..	..
26	..	..	5	..
27	..	..	3	..
28	..	..	..	..
29	..	..	..	..
30	10	..	..	..
31	..	..	..	..
TOTAL No. of cloudy days	7	..	16	..
TOTAL No. of rainy days	..	*Nil*	..	2
TOTAL Rainfall in inches	..	*Nil*	..	0·06

Appendix III.

Statement showing the number of cloudy days, cloud amount and the rainfall in inches at Lyallpur for the months of November and December during the year 1927-28.

Date	November		December	
	Cloud amount	Rainfall in inches	Cloud amount	Rainfall in inches
1	..	..	..	..
3	..	..	10	..
3	..	..	10	..
4	..	..	..	..
5	..	..	..	..
6	..	..	10	..
7	10	..	10	..
8	..	..	10	..
9	..	..	10	..
10	..	..	10	..
11	..	..	10	..
12	..	..	10	..
13	..	..	2	..
14	..	..	10	..
15	..	..	10	..
16	..	..	..	..
17	..	..	..	..
18	2	..	10	..
19	10	..	10	..
20	..	..	10	0·18
21	..	..	10	..
22	..	..	..	..
23	..	..	..	..
24	..	..	5	..
25	10	..	7	..
26	2	..	10	..
27	..	..	10	..
28	10	..	2	..
29	4	..	10	..
30	..	..	10	..
31	..	..	10	0·25
Total — No. of cloudy days	7	..	24	..
Total — No. of rainy days	..	*Nil*	..	2
Total — Rainfall in inches	..	*Nil*	..	0·43

APPENDIX IV.

Statement showing the number of cloudy days, cloud amount and the rainfall in inches at Lyallpur for the months of November and December during the year 1928-29.

Date	NOVEMBER		DECEMBER	
	Cloud amount	Rainfall in inches	Cloud amount	Rainfall in inches
1	..	..	10	..
2	..	..	10	..
3	..	..	7	..
4	..	..	..	..
5	..	..	..	..
6	..	..	10	..
7	10	..	10	..
8	8	..	..	..
9	10	..	..	..
10	2	..	10	..
11	10	..	10	..
12	10	..	10	..
13	10	0·48	10	..
14	2	0·67	10	..
15	..	..	..	..
16	..	..	..	..
17	..	..	10	..
18	10	..	..	..
19	..	..	..	..
20	..	..	..	..
21	..	..	..	..
22	10	..	..	..
23	..	..	..	..
24	..	..	..	..
25	4	..	..	..
26	10	..	10	..
27	10	..	10	..
28	10	0·30	10	0·04
29	10	0·69	10	..
30	10	..	10	..
31	..	..	..	..
TOTAL No. of cloudy days	16	..	16	..
TOTAL No. of rainy days	..	4	..	1
TOTAL Rainfall in inches	..	2·14	..	0·04

Appendix V.

Statement showing the number of cloudy days, cloud amount and the rainfall in inches at Lyallpur for the months of November and December during the year 1929-30.

Date	November		December	
	Cloud amount	Rainfall in inches	Cloud amount	Rainfall in inches
1	..	..	..	..
2	8	..	..	..
3	..	..	10	..
4	..	..	10	..
5	2	..	10	..
6	..	..	4	..
7	..	..	..	..
8	..	..	10	..
9	10	..	10	..
10	4	..	10	..
11	10	..	10	0·21
12	10	..	10	0·04
13	10	..	10	0·02
14	..	..	10	..
15	10	..	10	..
16	..	..	..	..
17	..	..	10	..
18	..	..	10	..
19	..	..	10	0·20
20	..	..	8	0·25
21	..	..	..	..
22	..	..	..	..
23	..	..	..	..
24	..	..	8	..
25	..	..	10	..
26	..	..	..	..
27	..	..	2	..
28	3	..	..	..
29	10	..	..	..
30	8	..	10	..
31	..	..	10	..
Total — No. of cloudy days	11	..	21	..
Total — No. of rainy days	..	*Nil*	..	5
Total — Rainfall in inches	..	*Nil*	..	0·72

SELECTED ARTICLE

STERILITY IN RICE HYBRIDS.*

BY

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(Reprinted from the *Journal of the American Society of Agronomy*, Vol. 22, Number 10; October 1930.)

There are hundreds of locally-adapted rice varieties in the principal rice-producing countries of the world. The numerous varieties of this crop probably came into existence in three ways, *viz.*, by natural crossing, by mutation, and by the selection and preservation of desirable forms by man. Some rice varieties yield and mill well, whereas others are of low yielding capacity and of poor quality.

CYTOLOGICAL STUDIES.

Kuwada (1)† counted the chromosomes in pollen mother-cells of common (*Oryza utilissima* Kcke.) and glutinous (*Oryza glutinosa* Lour.) rice varieties and found that the haploid number is 12 in both groups.

Nakatomi (2) made a cytological study of the chromosome number in the pollen mother-cells of 21 races and mutations of foreign and domestic rices and his results also show that the haploid number is 12. The size of the chromosomes varied in different varieties. Rau (3), in a cytological study of the root-tips of two domestic (South India) rice varieties and one variety from Madras, found that the somatic chromosome number is 24. He observed that there were three small, four intermediate, and five large chromosome pairs in the cells of the root-tips. The large chromosomes were about twice as long as the short ones.

These cytological studies of rice indicate that probably all cultivated varieties have 24 chromosomes in the somatic cells.

STERILITY IN RICE CROSSES.

During the past two decades many papers have been published dealing with the mode of inheritance of various characters in rice crosses. The genetic studies

* Contribution from the Office of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Department of Agriculture, in co-operation with the California Agricultural Experiment Station.

† Reference by number is to "Literature Cited", p. 867.

often are by-products of general rice improvement programmes in which hybridization is used.

In the rather extensive studies on rice hybridization, which have been conducted in recent years in the various rice-producing countries, only one paper is known to the writer in which a marked degree of sterility in the hybrids is reported.

Kato, *et al* (4) on the basis of morphological differences in rice varieties and sterility in crosses between certain varieties, conclude that the cultivated varieties of rice may be placed in two groups, designated as " Japonica " and " Indica." Varieties of both groups and crosses of varieties within each group exhibit a high degree of fertility, whereas crosses between varieties of the " Japonica " and " Indica " groups show a marked degree of sterility. They found that pollen formation in hybrids between varieties of the two groups was abnormal, and that a high percentage of the pollen grains was non-functional.

In F_2 generations the progeny from crosses of varieties within each group showed normal fertility, whereas in the progeny from crosses between varieties of the two groups the percentage of sterility was high although it varied materially. Kato and others conclude that the morphological differences present in the varieties of the two groups and the sterility observed in crosses between them indicate that they may be considered as being only distantly related in descent.

The cultivated rices of the " Japonica " group are believed to be native to Japan (proper), Korea, and North China, and those of the " Indica " group apparently are native to Formosa, Southern China, India and Java. In Central China while most of the cultivated rices belong to the " Indica " group, some varieties belonging to the " Japonica " group also are found.

Material and Results.

Varieties of rice belonging to these two groups were used in the experiments reported in this paper, as follows: " Japonica " group, hereafter referred to as " Japanese varieties "—Caloro, Wataribune, Colusa, Bungo and Aikoku; "Indica" group, hereafter referred to as " Chinese varieties "—C. I. 7022, C. I. 7075, C. I. 7078, C. I. 7389, C. I. 5315, and probably red rice.*

In 1924, the crosses Caloro × C. I. 5315 and Wataribune × red rice were made at the Biggs Rice Field Station. The F_1 plants were grown in 1925, but failed to set or mature seed. The writer was absent from the station in the fall of 1925 and no notes were taken on the character of the F_1 plants, except that they failed to set or mature seed.

In 1926, the crosses Caloro × C. I. 5315 and Caloro × red rice were made. Caloro was used as the female parent in both crosses in 1926 replacing Wataribune in the cross with red rice. The F_1 plants of both crosses, consisting of eight and

*C. I. refers to accession number of the Office of Cereal Crops and Diseases, formerly the Office of Cereal Investigations.

ten plants, respectively, were grown in 1927 in rows spaced two feet apart, with the plants spaced one foot apart in the rows.

The F_1 plants were vigorous and in morphological characters more like the male parents than the female parent. In growth habit the F_1 plants were more spreading, produced more culms, had wider leaves, and the panicles were less dense than for the Caloro variety. One of the F_1 plants produced 56 culms and all tillered freely. On September 30 some of the main culms of the F_1 plants had reached the booting stage. On November 3 panicles were partly exserted from the sheaths, but no seed was set on any of the F_1 plants, although Caloro, the latest maturing parent in both crosses, was fully matured on October 8. The stigmas appeared to be normally developed in the hybrid spikelets; the pollen, however, was poorly developed and apparently non-functional. The spikelets bloomed normally, but little or no pollen was found on the stigmas, and, due to lack of fertilization, the glumes did not interlock after blooming.

In November, 1927, before frost occurred, one F_1 plant of each cross was dug up, and these were placed in galvanized buckets. The two F_1 plants were then grown until spring by J. E. Morrow in a greenhouse of the U. S. Plant Introduction Garden at Chico, Calif. In the greenhouse both plants produced many culms which headed and bloomed during the winter months, but none of the spikelets set seed. In May, 1928, the two F_1 plants were returned to the Biggs Rice Field Station. Each plant was divided into five parts, and, after the tops had been cut off, the plants were transplanted in the rice nursery. They soon became established in the nursery and began to head and bloom in June, before the earliest varieties in the nursery had reached the heading stage. In July both hybrids matured seed, and, although both showed a high degree of sterility, enough matured seed was obtained for adequate F_2 progenies. The F_1 plants of the cross Caloro $\times$ red rice showed less sterility than those of Caloro $\times$ C. I. 5315. The matured seed of F_1 plants of the cross Caloro $\times$ red rice had red seed-coats like the male parent.

In the fall of 1927 four crosses were made between the Chinese varieties C. I. 7022, C. I. 7075, C. I. 7078, and C. I. 7389, which were collected in China in 1925, as female parents, and the Japanese varieties Caloro and Colusa as male parents. These crosses are listed in Table I and the dates of first heading, first ripening, and ripening of the parent varieties and the F_1 plants are given. Data on two crosses, Bungo $\times$ Caloro and Colusa $\times$ Aikoku, in which both parents are Japanese varieties, are also included in Table I. The data presented for the crosses Caloro $\times$ red rice and Caloro $\times$ C. I. 5315 are for the year 1927; for all other varieties and crosses the data are for the year 1928. All F_1 plants in crosses between Chinese and Japanese varieties were as late as or later than the latest parent. In only one cross between a Chinese and a Japanese variety, C. I. 7075 $\times$ Colusa, did the F_1 plants reach full maturity, whereas in the crosses, Bungo $\times$ Caloro and Colusa $\times$ Aikoku, in which both parents are Japanese varieties, the F_1 plants behaved in a normal

manner. In date of maturity the F_1 plants from the cross Bungo × Caloro were intermediate, whereas in the cross Colusa × Aikoku, both early maturing varieties, the F_1 plants were nearly three weeks later than either parent. F_1 plants which are as late as or later than the latest parent are by no means unusual in rice crosses grown at Biggs.

TABLE I.

Average dates of first heading, first ripening and ripening of the parent varieties and the F_1 plants of eight rice crosses grown at Biggs, Calif., in 1928.

Parents and F_1 plants	First headed	First ripe	Ripe
C. I. 7022	August 28th	September 28th	Did not fully mature.
Caloro	August 18th	September 13th	October 5th.
F_1 plants	August 25th	September 24th	Did not fully mature.
C. I. 7075	August 12th	September 6th	September 26th.
Colusa	August 8th	August 30th	September 19th.
F_1 plants	August 12th	September 6th	September 26th.
C. I. 7389	August 16th	September 4th	September 21st.
Caloro	August 18th	September 13th	October 5th.
F_1 plants	September 19th	Late October	Did not fully mature.
C. I. 7078	August 11th	August 29th	September 18th.
Caloro	August 18th	September 13th	October 5th.
F_1 plants	September 11th	Late October	Did not fully mature.
Caloro	August 25th	September 18th	October 8th.
Red rice	August 29th	September 13th	October 1st.
F_1 plants *	October 10th	....	Partly headed but no seed set or matured.
Caloro	August 25th	September 18th	October 8th.
C. I. 5315	August 19th	September 8th	October 1st.
F_1 plants *	October 14th	....	Partly headed but no seed set or matured.
Bungo	July 30th	August 23rd	September 6th.
Caloro	August 18th	September 13th	October 5th.
F_1 plants	August 12th	September 4th	September 18th.
Colusa	August 8th	August 30th.	September 19th.
Aikoku	August 13th	September 4th	September 20th.
F_1 plants	August 27th	September 25th	October 12th.

* The data given in Table I for the F_1 plants and parents for the crosses, Caloro×Red rice and Caloro× C. I. 5315, are for 1927.

In Table II is shown the percentage of sterility for the parent varieties and the F_1 plants grown in 1928, and the F_2 plants grown in 1929. The percentage of sterility was determined from counts of all filled and blank spikelets on 10 panicles, selected at random, of each parent and each F_1 progeny, except for the crosses Caloro × C. I. 5315 and Caloro × red rice, in which the counts were made on 6 and 5 F_1 panicles, respectively. The percentage of sterility in the F_2 plants was determined by counting all filled and blank spikelets on the main panicles from 10 to 63 random plants of each cross. Plants which were likely to be sterile as a result of late maturity were not used in these counts.

TABLE II.

Average percentage of sterility in the parent varieties and the F_1 plants grown in 1928, and the F_2 plants grown in 1929, of eight rice crosses at Biggs, Calif.

Female parent	Percentage of sterility	Male parent	Percentage of sterility	Percentage of Sterility	
				F_1 plants	F_2 plants
C. I. 7022 . .	6·22	Caloro .	2·06	52·61	19·84
C. I. 7075 . .	6·86	Colusa .	2·97	70·39	34·56
C. I. 7389 . .	7·93	Caloro .	2·06	61·72	26·98
C. I. 7078 . .	5·38	Caloro .	2·06	61·75	40·98
Caloro . .	2·15	C. I. 5315 .	9·61	83·61	39·88
Caloro . .	2·06	Red rice .	5·32	28·89	48·56
Average . .	5·10	..	4·01	59·83	35·13
Bungo . .	5·77	Caloro .	2·06	3·63	4·72
Colusa . .	2·97	Aikoku .	5·12	3·16	2·89
Average . .	4·37	..	3·59	3·40	3·31

The sterility in the parent varieties ranged from 2·06 per cent. for Caloro to 9·61 per cent. for C. I. 5315. The F_1 plants of crosses between Chinese and Japanese varieties ranged in sterility from 28·89 per cent. for the cross Caloro × red rice to 83·61 per cent. for the cross Caloro × C. I. 5315. All F_1 plants in which red rice and the Chinese varieties were used as parents exhibited a comparatively high percentage of sterility, whereas the F_1 plants from the crosses Bungo × Caloro and Caloro × Aikoku, all Japanese varieties, were fully as fertile as the parent varieties. Crosses between Chinese varieties should be as fertile as the parents, and Kato, *et al* (4)

state that they were. We have no information bearing on this subject, however.

In the F_2 plants from the crosses under consideration, in which one parent was a Chinese variety or red rice, the average percentage of sterility ranged from 19·84 in the cross C. I. 7022 × Caloro to 48·56 in the cross Caloro × red rice, and the average for all five crosses was 35·13 per cent. The F_2 plants from the crosses Bungo × Caloro and Colusa × Aikoku were equally as fertile as the F_1 and the parent plants.

In Table III is shown the number of random F_2 plants from each cross in which all spikelets on the main panicles were counted, the range in the percentage of fertility, and the numbers of F_2 plants in each cross that matured seed, that headed but failed to mature seed, and that failed to head.

TABLE III.

Range in percentage of fertility of F_2 plants and the number of F_2 plants that matured seed, that headed but failed to mature seed, and that failed to head, of eight rice crosses grown at Biggs, Calif., in 1929.

Cross	No. of panicles counted*	Range in percentage of fertility of F_2 plants		Matured		F_2 plants with green panicles		Failing to head	
		Low No.	High per cent.	No.	per cent.	No.	per cent.	No.	per cent.
C. I. 7022 × Caloro	25	21·95	100·00	508	92·4	42	7·6	0	0·0
C. I. 7075 × Colusa	40	5·56	96·72	618	99·7	2	0·3	0	0·0
C. I. 7389 × Caloro	10	56·84	92·86	358	72·6	123	25·0	12	2·4
C. I. 7078 × Caloro	63	53·33	97·01	473	89·2	57	10·8	0	0·0
Caloro × red rice	11	10·35	93·33	216	38·4	240	42·7	106	18·9
Caloro × C. I. 5315	11	12·20	91·46	50	22·8	74	33·6	96	43·6
Bungo × Caloro	10	89·74	100·00	All	100·00	None	0·0	None	0·0
Colusa × Aikoku	10	93·10	100·00	All	100·00	None	0·0	None	0·0

* The number of spikelets per panicle ranged from 40 to 259.

The minimum range in fertility varied from 5·56 to 56·84 per cent. in the crosses C. I. 7075 × Colusa and C. I. 7389 × Caloro, respectively. The maximum range in fertility varied from 96·86 to 100 per cent. in the crosses C. I. 7389 × Caloro and C. I. 7022 × Caloro, respectively.

In the crosses Bungo × Caloro and Colusa × Aikoku, Japanese varieties, the minimum and maximum range in fertility was from 89·74 to 100 per cent. Some of the F_2 plants from crosses between the Japanese and Chinese varieties were as fertile, or nearly as fertile, as the parent varieties and such results are expected.

In the F_2 plants of the cross Caloro × C. I. 5315 only 22·8 per cent. of the plants matured seed, while in the cross C. I. 7075 × Colusa 99·7 per cent. matured seed. The percentage of F_2 plants that did not fully head and failed to mature seed ranged from 0·3 for the cross C. I. 7075 × Colusa to 42·7 per cent. for the cross Caloro × red rice. The percentage of F_2 plants that failed to head ranged from 2·4 in the cross C. I. 7389 × Caloro to 43·6 per cent. for the cross Caloro × C. I. 5315.

Discussion.

The cytological studies on rice, which were reviewed earlier in this paper, indicate that probably all cultivated varieties of rice have the same number of chromosomes. Likewise, all cultivated rice varieties (*Oryza sativa*) usually are considered as belonging to a single species. It seems logical to expect, therefore, that in rice crosses the hybrids should be as fertile as the parent varieties. Rau (3) states that " there has not been so far any reported case in which difficulty was experienced in crossing or sterility was observed in the offspring in the very extensive series of crossing-experiments to which different varieties of this plant (rice) have been subjected." He evidently had not seen the paper by Kato, *et al* (4) when this statement was made.

The data presented in this paper concerning the behaviour of F_1 and F_2 plants from crosses between Japanese and Chinese rice varieties show that there is a marked degree of sterility in the offspring from these crosses. In addition to the sterility observed the development of the plants was abnormal, as is shown by the large number of F_2 plants which were so late that they failed to head and of those which headed but failed to mature seed.

The characteristic late maturity or failure to mature fully in the F_1 plants and the failure of many F_2 plants even to reach the heading stage, in the crosses under consideration, is certainly unusual in varietal crosses. This abnormal behaviour may be due in part to the action of genetic factors for late maturity, some of which entered the crosses from both parents. However, if factors for late maturity were present in the parent varieties they were recessive to factors for earliness, for none of the parental varieties are really late-maturing rices. It seems more reasonable, therefore, to assume that the sterility and lateness observed in the F_1 and F_2 plants are probably due to incompatibility in the chromosome mechanism which prevented normal functioning and development of the hybrid plants.

Conclusion.

The results presented in this paper tend to support the idea advanced by Kato and others that the cultivated varieties of rice belong to two types, " Japonica " and " Indica," which are only distantly related in descent.

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2. Nakatomi, Sadao. Differences of chromosomes in various races and mutants of rice (trans. title). *Indengaku Zassa* [*Japanese Journal of Genetics*] **2,** 107-115, figs. 2; 1923. Abs. in *Bot. Abs.* 14, 807, 1925.

3. Rau, N. S. Further contributions to the cytology of some crop plants of South India. *Jour. Indian Bot. Soc.* **8,** 201-206, 1929.

4. Kato, Shigemoto, Kosaki, Hirosi, and Hara, Shiroru. On the affinity of rice varieties as shown by the fertility of hybrid plants (trans. title). English résume pp. 146-147, 1928. Note: Contribution from the Agronomical Institute, Kyushu Imp. Univ. Nov. 6, 1928. *La Bulteno Scienca de la Fakultato Terkultura, Kjusa Imperia Universitato Fukuoka*, Japannjo **3,** 132-147, 1928.

ABSTRACTS

[We are indebted to " Archivos do Instituto Biologico de Defesa Agricola e Animal " (Sao Paulo—Brazil), Vols. I, and II, for the following abstracts of articles published therein. The original articles, which are in Spanish, are available for reference in the Library of the Imperial Council of Agricultural Research, New Delhi.]

DOENCA BACTERIANA DA BATATA.—GENESIO PACHECO. VOL. I, PP. 69–82.

There is described an epiphytal disease of the potato (*Solanum tuberosum*), observed at Monte-Mor, township of Campinas, State of S. Paulo, Brazil.

The disease broke out in a lot of these tubers stored in a warehouse, and caused a dark-coloured, soft rot with a smell like that of salt herring.

A microscopical examination of the damaged tubers showed the existence, predominantly in the exclusive and softened mass at the points where the lesion began, of a species of bacterium with the microscopic characteristics of the tribe *Erwiniae* of the American Commission of Bacteriologists, described in Bergey's manual (2).

The isolated bacterium, by its cultural, morphological and physiological characters, could be identified as a species participating of the characters of *Erwinia melonis* and *E. solanisapra*, especially the latter.

It differs from *E. melonis* because it melts gelatine slowly (15 days), forming a dome; it forms regular colonies; it forms a pellicle and darkens the broth; it does not form indol; it ferments lactose slowly (48 hours), without producing gases and is microaerophylous.

It differs from *E. solanisapra* merely by the slow fermentation of lactose without gas production, it is provided with 4-6 cilia and is microaerophylous. Adopting the opinion of Smith, who consider the species *melonis* and *solanisapra* identical, for these the name *solanisapra* should have precedence, by right of priority. Thus the bacterium isolated by the author is identical with this species.

The experimental infection of the tubers was obtained by inoculating the bacterium deeply and by keeping the tubers in a moist atmosphere, a high temperature (21°C), and having them protected from light.

It was verified that aeration, illumination and drying paralized the infection already begun, while a suppression of these conditions caused renewed activity of the bacteria.

A histological study is made of the pathological alterations in fragments fixed in alcoholic sublimate and stained by the Gram and Gram-MacCallum methods. It was verified that the infection begins and progresses at the cost of the bacterium isolated, which substitutes the grains of starch in the cells transformed into deposits of this substance.

After the nutritive substance has been exhausted, the bacteria begin to grow rarer and nearly disappear completely; when the bacteria of the secondary infection begin to appear. By the action of these, there is determined the destruction of the cellulose and the final fusion of the attacked portions. The observation of the cuts shows a lysis of the starch grains in a zone where the bacteria have not yet appeared. In the experimental infection there is a simultaneous attack on a large surface, so that all of the aspects are found in concomitancy.

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PRAGA DOS BAMBUS—RHINASTUS STERNICORNIS (GERM.).—ED. NAVARRO DE ANDRADE. VOL. I, PP. 137—142.

This insect was found for the first time in the State of Santa Catharina, where it was attacking the giant cane (*Chusquea gaudichaudi* Kunth). Subsequently its destructive work was observed in Rio Claro, State of S. Paulo, where it attacked the common bamboo (*Bambusa vulgaris* Schrad), the Imperial bamboo (*Phyllostachys castillonis* Mitf), the crissiuma cane (*Chusquea* sp.), the small cane (*Arundinaria* sp.), various other canes (*Merostachys*), and the Indian bamboo (*Bambusa arundinacea* Retz). The giant bamboo (*Dendrocalamus giganteus* Munro) was not attacked, which should be attributed to the thickness of its stalk.

The females puncture the young bamboo shoots, always less than a year old, depositing one egg in each perforation. The eggs usually hatch within 6 to 10 days; 15 days being the maximum observed. The larval state lasts about three months. Usually 6 to 10 larvae are found in each internode, but the number varies greatly; and as they attain their development, the larger devour the smaller ones, until finally but one larva remains in each internode.

In Rio Claro adults have been captured during different months of the year, however they become more common during January and attain their maximum abundance during March.

Copulation is very prolonged and can continue up to 36 hours. After copulation the insects live, on an average, 7 to 8 days. About 50 per cent. of the adults are males.

The best means of combating this pest consists in opening the infested stems, always before the month of September, and exposing them, thus opened, to the sun. The larvae can resist the sun's rays but a few minutes.

SYNEURA INFRAPOSITA *Borgm.-Schmitz* (DIPTERA, PHORIDAE)—UM NOVO PARASITA DA ICERYA PURCHASI *Mask.*—MARIO AUTUORI. VOL. I, PP. 193—200.

The present paper represents a contribution to the biology of *Syneura infraposita* Borgm.-Schmitz, a little fly of the family *Phoridae*, which parasites the adults of *Icerya purchasi* Mask. A detailed description of the larva and pupa is here given for the first time, thus increasing our knowledge of the development of the various phases until now unknown of the genus *Syneura*.

ALGUNS NEMATODES PARASITAS E SEMI-PARASITAS DAS PLANTAS CULTURAES DO BRASIL.—PROF. DR. GILBERT RAHM, O.S.B. VOL. I, PP. 239—252.

The present communication has to be considered as a preliminary note, and is only an attempt to give an idea of the different forms of free living, parasitic and semi-parasitic nematodes,

found on various cultivated plants of Brasil. The full observations and the detailed descriptions of the forms here studied will be given in the next volume of this *Archivos*. The genera *Tylenchus* and *Heterodera* are considered as including the real *parasitic nematodes*. The *Diplogaster rhizophilus* which was found on several plants, may also be considered as a form, that can damage cultivated plants. Some experiments were made with the purpose of infecting the roots of the coffee-tree with this species; but if it really attacks this plant, I am not able to say at present, as the time available for these experiments was too short.

NEMATODES PARASITAS E SEMI-PARASITAS DE DIVERSAS PLANTS CULTURAES DO BRASIL—PROFESSOR DR. GILBERT RAHM, O.S.B. VOL. III, PP. 67—136.

The author presents, in this work, the result of some researches made during his stay in S. Paulo, at the end of the year 1928 and intends to give an idea of the various forms of free-living nematodes, either parasites, or semi-parasites, of several cultivated plants of Brazil. A previous note on the subject was already published in the 1st volume of these "Archivos". Now the completed work follows, accompanied by 108 drawings and 37 photographs, printed on 11 plates.

Part A of the work deals with the classification of the forms studied. Of the described nematodes: 12 infest the roots of the coffee-tree, being 7 species, 4 var. and 1 subform; 2 species, 1 var. and 1 subform live in the leaves of the coffee-tree; 6 species, 1 var., 1 form and 1 subform live in the roots of the banana plant; 10 species, 3 var. and 1 form live in the fruits and flowers of the banana plant; 3 species and 1 var. attack the roots of the orange tree (*Citrus aurantiacum*); 6 species live in the leaves of the orange tree; 3 species, 2 var. and 1 subform in the sugar-cane and 3 others, more especially in the invaginations of the sugar-cane, 5 species in the roots of cassava (*Manihot utilissima*); 4 species and 1 subform in potato tubers (*Solanum tuberosum* L); 4 species in the bulb of the onion; 5 species and 2 var. in the roots of *Dianthus cariophyllus* L; 4 species and 1 var. in moss; and finally 1 species and1 subform in the roots of the cotton plant (*Gossypium herbaceum* L).

In part B of the work, the author relates the biological and physiological observations he realised; 1st, on parasitism and semi-parasitism; 2nd on the resistance of root nematodes to desiccation; 3rd on the multiplication and abundance of nematodes; 4th on the ravages caused by nematodes; 5th on methods of combating these pests.

REVIEW

Index to the Literature of Food Investigation, Vol. 2, No. 1, March 1930. —Compiled by Agnes E. Glennie, B.Sc., and published by the Director of Food Investigation, Department of Scientific and Industrial Research. (H. M. Stationery Office) Price, 2 shillings net.

This is the third of the lists of 'elaborated titles' of literature on food research issued by the Low Temperature Research Station, Cambridge, in fulfilment of the recommendation of the Imperial Research Conference, 1927, that research institutions in the Empire should be kept abreast of progress in preservation and transport of food in this manner. In addition to a classified list of nearly 1,000 references, with substantial abstracts in many instances, the volume contains a most valuable review of noteworthy developments during 1928-29.

The index should be of great assistance to physiologists and biochemists in general as well as to those more immediately concerned in the problems of food transport and storage.

In his prefatory note Sir William Hardy draws attention to the fact that only to the extent to which publications relating to the preservation and transport of food as well as enquiries, criticisms and suggestions are sent to the Superintendent, Low Temperature Research Station, Cambridge, that workers in different parts of the Empire can be assisted and put in touch with each other. [B. C. B.]

THE IMPERIAL AGRICULTURAL BUREAUX.

The following publications and communications bearing on crops and soils have been received by the Imperial Council of Agricultural Research from the Imperial Agricultural Bureaux mentioned. Research workers who have not received copies of communications dealing with their special subject are invited to communicate with the Council.

Imperial Bureau of Soil Science.

Technical Communications.

No. 1. The Present Position of the International Method of Mechanical Analysis.
No. 2. The Examination of Organic Matter in Soils.
No. 3. Preliminary Soil Map of the Empire.
No. 4. A Summary of a Report (by H. H. Croucher) of some cultivated St. Lucia Soils.

No. 5. Soil Erosion (with Bibliography).
No. 6. The American System of Soil Classification and Survey, by L. L. Lee.
No. 7. Method of taking Soil Profiles.
No. 8. Publications on Soil Science issued from the Empire Overseas during 1929.
No. 9. The Colorimetric Determination of Phosphoric Acid in Soils.
No. 10. The Arrangement of Field Experiments and the Statistical Reduction of the Results, by R. A. Fisher and J. Wishart.
No. 11. Note on an area of Alkali land in Western Australia.
No. 12. Determination of Exchangeable Bases and Lime Requirement.
No. 13. The Second International Congress of Soil Science.

Reports.

1. Report of the Imperial Bureau of Soil Science for the year ending 31st March, 1930.
2. Report on a tour of certain German Experimental Stations engaged in research on soils and fertilizers, etc., compiled by Dr. E. M. Crowther, of the Rothamsted Experimental Station.

Publications.

1. Soils and Fertilisers, by Dr. E. M. Crowther. Reprint from Reports of Progress of Applied Chemistry, 1929.
2. Circular regarding the British Empire Section of the International Society of Soil Science.

IMPERIAL BUREAU OF PLANT GENETICS (HERBAGE PLANTS).

Bulletins.

1. Bulletin No. 1, Miscellaneous Information relating to breeding of Herbage Plants (with Supplement), March, 1930.
2. Bulletin No. 2, Miscellaneous Information relating to Herbage Plants, September, 1930.

Publications.

1. List of papers translated for the Welsh Plant Breeding Station to December, 1929 and available on loan from the Imperial Bureau of Plant Genetics (Herbage Plants).
2. Herbage Research Circular No. 1, October, 1930.
3. Herbage Research Circular No. 2, November, 1930.
4. Abstracts of important articles.
5. Current Literature, October. 1930.

IMPERIAL BUREAU OF PLANT GENETICS (FOR CROPS OTHER THAN HERBAGE).

1. A short account of the functions of the Bureau.

Publications and Bibliographies.

1. Papers on Plant Genetics received from January to June, 1930, Parts I and II.
2. Wheat Breeding Bibliography, Parts I and II.
3. Barley Breeding Bibliography.

IMPERIAL BUREAU OF FRUIT PRODUCTION.

Technical Communication.

No. 1. Ringing Fruit Trees, the present position, by D. Akenhead.

Publication.

1. Imperial Bureau of Fruit Production—Horticultural Research work in the Empire.

BRITISH EMPIRE SECTION OF THE INTERNATIONAL SOCIETY OF SOIL SCIENCE.

The following circular is issued by the Imperial Bureau of Soil Science at the request of the British Empire Section of the International Society of Soil Science for the information of those who are not already members of the Society :—

At a Joint Meeting of the Conference of the Imperial Bureau of Soil Science and the above body in September 1930, it was apparent that a number of Overseas Soil Workers were not aware of the existence of the British Empire Section of the International Society of Soil Science. The present opportunity is therefore being taken to bring before such people a brief statement of the work of the Section and its parent body.

The International Society of Soil Science was inaugurated in Rome in 1924 and has held two successful Congresses, in Washington in 1927 and in U. S. S. R. in 1930. The third International Soil Congress will be held in England in 1935. The Society has two periodicals, (*a*) " Proceedings " issued four times per annum and consisting chiefly of abstracts of which many are from sources not generally available owing to language difficulties and (*b*) " Soil Research " issued less frequently and containing full papers. These Journals are issued only to members.

The Society conducts its business through six Commissions and a number of Sub-Commissions. Members of the Society may become members of any (or all) of the Commissions. A year or so before a full Congress, the Commissions hold separate Conferences to prepare reports to the Congress, to arrange co-operative work, and to hold technical discussions. In 1929 four volumes of papers and reports from such Conferences were issued without charge to all members of the Society in addition to the usual publications. The Transactions of the Congresses are available to members at greatly reduced rates.

The Society is endeavouring to secure agreed conventions and standard procedure in analytical methods in all cases in which some arbitrary factor enters, such as grades of particle size in mechanical analysis, ratio of soil to solution in reaction measurements and acid extraction. It is also attempting to develop and co-ordinate soil surveys throughout the world and has already published a Soil Map of Europe on a scale of 1 : 10,000,000 and made considerable progress with one on a scale of 1 : 15,000,000 which should be completed in about three years.

The Society has many National Sections each of which has separate representatives on the General Committee of the Society. South Africa has already formed a National Section, the rest of the Empire is included in the British Empire Section, which has at present about 120 members divided about equally between the British Isles and Overseas.

The present Officers of the British Empire Section are :—

President : Prof. N. M. Comber.
Secretary : Dr. E. M. Crowther.
Committee : Mr. G. R. Clarke.
Dr. W. G. Ogg.
Prof. G. W. Robinson.

It is obviously desirable that the membership of the British Empire Section should be as complete as possible well in advance of the next Soil Congress.

The British Empire Section generally holds two meetings a year in conjunction with the Agricultural Education Association, but in 1930 two meetings were held at other times so as to secure the attendance of workers unable to attend the A. E. A. meetings. It is hoped in the future to hold at least one meeting annually at a time suitable for Overseas workers temporarily in England.

The subscription for 1931 has been fixed as in recent years at £1 (with an entrance fee of 4/6 for new members). All British Empire members should pay their subscriptions to the Secretary, Dr. E. M. Crowther, Rothamsted Experimental Station, Herts, and not to the General Secretary of the Association.

APPENDIX.

INSTRUCTIONS TO AUTHORS OF PUBLICATIONS OF THE IMPERIAL COUNCIL OF AGRICULTURAL RESEARCH.

1. All manuscripts should be clean, clear and carefully revised. Only one side of the paper should be used, and as far as practicable the original type-written copy and not a carbon copy should be sent. Capitals should be sparingly used, and all the necessary punctuation should be done in the MS. and not left for introduction in proofs.

2. The title of a paper should not be lengthy.

3. It is desirable that the MS. should have suitable heads and sub-heads. In numbering the principal divisions of a paper roman numerals should be used. The use of arabic figures and (*a*), (*b*), (*c*), etc., is generally reserved for numbering the sub-divisions coming under each head.

4. Articles submitted for publication either in the "Indian Journal of Agricultural Science" or in the "Indian Journal of Veterinary Science and Animal Husbandry" should be accompanied by abstracts for publication in "Agriculture and Live-stock in India." Abstracts should be concise, but should be long enough to explain the matter dealt with; ordinarily no abstract should exceed 200 words.

5. When a word or line is intended to be printed in *italics* it should be underlined with a single line, in SM. CAP. with two lines, in CAPITALS with three lines, and when in **antique** (heavy type) with a wavy line (~~~~~~~~~~).

6. In descriptive matter, numbers under 100 and all numbers occurring at the beginning of a sentence should be in words.

7. Local names for crops, technical operations, etc., should be defined where they first occur in the text, *e.g.*, *rabi* (spring crop). The use of local weights and measures should be avoided as far as possible. Vernacular names, such as *jowar*, *bajri*, should be in italics without a capital letter, and each such name where it first occurs should be followed by its scientific equivalent in brackets, *e.g.*, *jowar* (*Andropogon Sorghum*). It is usual to write the initial letters of varietal names in capitals, *e.g.*, Striped Mauritius, Dharwar-American cotton and Broach cotton.

8. Botanical and zoological names are printed in italics and should be underlined in the MS., *e.g.*, *Triticum vulgare* L., *Diplodia Corchori* Syd., *Pyrilla aberrans*, Kirby. The International rules of Botanical nomenclature and the International rules of Zoological nomenclature should be followed. The names of chemical substances should not be written with a capital letter; they are printed in roman type (*e.g.*, calcium carbonate, prussic acid).

9. The following and similar abbreviations may be used freely :—*viz.*, *e.g.*, *i.e.*, mm. (millimetre), cm. (centimetre), grm. (gramme), mg. (milligramme), c. c. (cubic centimetre), sp. gr. (specific gravity), lb. (pound), cwt. (hundredweight), in. (inch), ft. (foot), oz. (ounce), md. (maund), sr. (seer), ch. (chattak). Other abbreviations should be used sparingly, if at all.

10. References to plates should be given within brackets, without prefixing the word " see " or " cf.", in the MS. itself, and should not be left over for introduction in proofs. For example, " The parasite (Pl. X, fig. 4) was present late in 1906."

11. The word " Table " is preferable to " Statement," and tables should be numbered consecutively in roman figures. Each table should have an explanation as a sub-head. It is more convenient for reference if tables can be printed horizontally ; for this purpose they should not exceed in width the printing measure of the page (5″).

Example—

TABLE IV.

Results of water-saving experiments on wheat (Pusa 12) at Gungapur, Haripur and Sargodha, 1916-17.

Station	No. of irrigations including the preliminary watering	Yield per acre in maunds and seers				Average yield per acre			
		Grain		Straw		Grain		Straw	
		mds.	srs.	mds.	srs.	mds.	srs.	mds.	srs.
Gungapur . .	one	12	19½	20	10	9	34	21	17
Haripur . .	„	8	31	19	14				
Sargodha . .	„	8	12½	25	27½				

12. References to literature, arranged alphabetically according to authors' names, should be placed at the end of the article, the various references to each author being arranged chronologically. Each reference should contain the name of the author, the year of publication, the abbreviated title of the publication, volume and page. In the text the reference should be indicated by the author's name followed by the year of publication enclosed in brackets ; when the author's name occurs in the text, the year of publication only need be given in brackets. If reference is made to several articles published by one author in a single year, these should be numbered in sequence and the number quoted after the year both

in the text and in the collected references. This system of referencing is used in the "Biochemical Journal" and will be clear from the following (illustration) :—

The work of Osborne and Mendel [1919, 1, 2] and Steenbock and Boutwell [1919] had indicated an association of the fat-soluble vitamin with the green parts of plants. This view was examined by Coward and Drummond [1921], who reported that vitamin A was not synthesised by etiolated shoots but that green leaves were active in its formation. Another worker [Wilson, 1922], on the other hand, found that etiolated shoots if given in sufficient quantity could supply the fat-soluble vitamin and that this factor was therefore formed in the absence of light.

REFERENCES.

Coward and Drummond (1921). *Biochem. J.* **15**, 530.
Osborne and Mendel (1919, 1). *J. Biol. Chem.* **37**, 187.
——————— (1919, 2). *J. Biol. Chem.* **41**, 549.
Steenbock and Boutwell (1919). *J. Biol. Chem.* **41**, 149.
Wilson (1922). *J. Biol. Chem.* **51**, 455.

Abbreviations, as far as possible, should follow the system adopted in "A World List of Scientific Periodicals" published by the Oxford University Press.

13. Papers should be complete when submitted for publication. As alterations and additions at the proof stage cause both additional expense and delay, they should be resorted to as little as possible. In making corrections in proofs the recognized symbols which will be found in the "Standard Dictionary" should be used. Second (page) proofs will be submitted to authors who should return them promptly.

Illustrations.

14. As the *format* of the journals has been standardized, the size adopted being crown quarto (about $7\frac{1}{8}'' \times 9\frac{5}{8}''$ cut), no text-figure, when printed, should exceed $4\frac{1}{2} \times 5$ inches. Figures for plates should be so planned as to fill a crown quarto plate—the maximum space available for figures being $5\frac{3}{4} \times 8$ inches exclusive of that for letter press printing.

15. Photos or drawings for illustration should accompany the manuscript and each should bear on the reverse side the name of the paper to which it relates together with the title or legend, figure or plate number, and the size to be reproduced. When giving instructions for reduction linear measurements are understood ; thus, "half-size" means reduce to half the length and breadth, not half the area. A photograph should not be rolled up, nor pinned, and should always be packed flat. A complete list of plates and figures should always accompany the paper.

16. Line drawings should be made with clear black lines on smooth white paper, preferably Bristol board. Rough paper should be avoided. Care should be taken that all the lines are drawn firmly ; scratchy or grey lines, produced by the ink being thinned down, are not permissible. Drawings should be larger than the required

size. All lettering should be neatly and clearly put in, care being taken to make all lettering sufficiently large to stand reduction.

17. For half-tone work, copy should be made on glossy silver paper and of the same size or larger than the size required.

18. For three-colour work, copy may be oil painting, water-colour, coloured photograph or coloured transparency, and larger than the size required. In preparing copy, one should use only the primary colours, in any combination, as only inks of primary colours are used in printing. Originals can be enlarged, if necessary, but this should be avoided if possible.

19. For detailed instructions regarding preparation of illustrations, it would be of advantage to refer to Mr. C. M. Hutchinson's article on "Photographic Illustrations" in the *Agricultural Journal of India*, Vol. XI, Pt. 3, July 1916, and Mr. A. W. Slater's paper on "The Preparation and Reproduction of Scientific Illustrations" in the *Proceedings of the Third Entomological Meeting*, 1919, which has been reprinted as *Bulletin No. 114 of the Agricultural Research Institute, Pusa*.

THE DETERMINATION OF QUALITY OF AGRICULTURAL PRODUCE, WITH SPECIAL REFERENCE TO COTTON.*

BY

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In the most primitive society, mankind's chief occupation is the satisfaction of his bodily needs. First and foremost he must obtain his food; hence his first concern is food, and the weapons by means of which he may obtain it. In a tropical climate he is less concerned about his clothing and his shelter, though in colder climates the rigours of Nature have compelled him to seek some means of shelter, such as a cave, and some means of keeping warm. But in his leisure moments, when his belly was full, even the untutored savage had some interest in the more ornamental things of life, arts and crafts. However, in the highly civilised life which we lead to-day there is far more diversification. Although vast numbers of people are unemployed at the present time, and find it difficult even to secure the bare necessities of life, yet there are multitudes who look beyond the bare necessities and seek to taste life in many other ways; and it is proverbial that the luxuries of one age become the necessities of the next. Man—and woman too—is no longer almost solely interested in the agricultural produce that he puts inside himself, but takes quite a considerable interest in the agricultural produce that he puts outside himself in the shape of clothing; moreover, he seeks not only to adorn his person but also to beautify his home; he is content to spend a great deal on those entertainments which appeal to his taste, and he requires to be transported from one part of the world to another; and in all these things he makes greater and greater demands upon agricultural products in general, and upon textile fibres and fabrics in particular. As experience of use increases so does demand become more critical, and those with long purses, while boasting that the best is good enough for them, explain that they are willing also to pay and to pay heavily for the best. It is the satisfaction of this demand which leads to the appreciation of "quality" and sets a premium upon it.

I have purposely dwelt upon the diversity in man's fundamental needs, because it may be noted that early man's predominating interest in food is paralleled by the

* Paper read at the Indian Science Congress, Nagpur, January 1931.

scientist's in the investigations and tests of recent times, which have undoubtedly been more exhaustive of foodstuffs than of the materials used for clothing. In the various markets for different commodities men have been trained by long experience to distinguish differences in quality of the raw materials, *e.g.*, rice, wheat, sugar, cotton, jute; and there is no doubt that in many cases they have acquired great skill in carrying out their work quickly and accurately. These methods are usually empirical and of course subjective, and it is therefore of little wonder that the attempt has been made either to replace or to supplement them by tests of a more scientific nature. But even the scientist has not been slow to make use of these empirical methods where they have served his purpose. Thus, Biffen and his assistants, when first carrying out their original researches leading to the production of "Yeoman" wheat, had in the first place to resort to the chewing test to decide which of the grains had the characteristics of hard wheat and which of soft wheat, the difference in the effect on chewing being attributed to a difference in the amount of gluten present, this being responsible for the hardness and the consequent effect on the baking of the loaf.

The individual senses are necessarily made use of in these empirical tests. Even in testing tallow for its quality, a weaving master will commonly use a chewing test and obtain a result of considerable accuracy. The tea taster does distinguish different qualities of tea. These are instances where the mouth is used to good advantage. In other cases the eye, the hand, or the nose play a part. But when the physicist wishes to determine quality scientifically, the use of the senses is generally confined to the reading (and recording) of observations on a scale. Thus the determination of the percentage content of sugar (sucrose) in a solution is easily and accurately done by means of the saccharimeter. Specific gravity is a physical constant frequently used for testing materials made from agricultural produce, and forms an important test in the case of beer and other liquids. More recently the spectroscope has been brought into the sphere of usefulness in the testing of foodstuffs, being applied to the detection of small quantities of metallic impurities.

But the testing of textile fibres rests on quite a different basis, and I propose to devote the remainder of this short paper to discussing this. The subjective and empirical means of distinguishing different types of cottons has necessarily existed in this case also and held the field alone and unchallenged until the past few years.

In a paper which I gave at the meeting of this Congress in Bombay in January 1926, I discussed the chemical and physical properties of cotton and referred to their several or joint relationship to the various processes of ginning, spinning, doubling, winding, warping, weaving, mercerising, bleaching, dyeing, and finishing. I pointed out that the most important criterion of the quality of a cotton is its

spinning value. Points observed by the cotton grader—such as impurity present, length, strength, and regularity of staple—are of importance because of their relation to the spinning value. The fibre has to be spun, and the grader relies on his estimate of these qualities as an indication of how it will spin. I showed that the limiting degree of fineness to which a fibre can be spun with greatest profit to the spinner is the governing criterion of spinning value ; at this limiting degree of fineness the yarn must have a certain minimum strength in order that it may be satisfactory in the later operations. As a practical test for the quality of a sample of cotton, therefore, we may displace the empirical test of the cotton grader by submitting the cotton to a spinning test, to see how it actually does behave in spinning. This test is invariably made on a sufficiently large sample submitted for test to the Technological Laboratory. But even this test is not so simple as it looks at first sight, and it is necessary to lay down a series of standards ; strength depends upon twist given in spinning ; economic working depends upon having few breakages during the spinning process. In testing a sample of cotton at the Technological Laboratory, therefore, it is spun with standard twist into three different counts, *i.e.*, degrees of fineness. The strengths of the spun yarns are determined, and on the results of these, as well as on observations of the behaviour of the cotton in the spinning process, the decision is based as to the highest standard warp counts for which the given cotton is suitable. As already remarked the process appears comparatively simple ; but nevertheless, it gives rise to many vexed problems :—The properties of the fibres are modified by the twist which binds them together, but the twist is never uniform in its distribution, the fibres are never equal in numbers in every part of a given yarn ; and the fibres do not make a constant angle with the yarn axis throughout the yarn. Even yarn-strength tests have been the subject of acute controversy ; it is generally admitted that the lea test commonly employed is not ideal, and Balls has pointed out that the distribution of twist in a yarn at the moment of breaking may differ considerably from that in the yarn when free from tension, and has come to the conclusion that the only really satisfactory method of determining the strength must include the testing of the given yarn using various lengths of specimen. This has also been the practice to some extent at the Technological Laboratory where tests are made on single threads 12 inches long as well as on leas each 120 yards long. There is no doubt that it is useful to have a single index of the spinning value of a cotton, and for this purpose the highest standard warp counts, based as it is on the lea strength, single thread strength, and number of yarn breakages in the ring frame, is probably the best single index at present available.

Here then is our practical test for determining the quality of cotton. Waste produced during the various spinning processes is a check upon the grading of the

material by the cotton grader, and this combined with the spinning value of the cotton is a check upon the grader's valuation.

It is the aim of the Technological Laboratory to go further than this, however. What we wish is to be able to predict the highest standard warp counts merely from an examination of the fibre-properties. The spinning test is satisfactory as far as it goes, for it bears the closest resemblance to actual practice. But it is an expensive test to make, and it requires a comparatively large amount of cotton, which can only be produced by a cotton breeder after some seasons' multiplication, and is therefore expensive of *his* time, labour, and land. The grader's test is ideal in being rapid and inexpensive, but it is liable to error ; for example, in judging one series of cottons he assigned a higher value to a cotton which only spun 20's yarn than to a cotton which spun 32's, even though the latter gave slightly less waste. What we desire, therefore, is to replace the grader's estimate (and market-valuation) of the fibre-properties by reliable physical measurements of them. I cannot here go into details concerning the physical measurements we make ; a brief description of the methods is given in " Technological Reports on Standard Indian Cottons ". Suffice it here for me to say that measurements have been and are made of the following fibre-properties : length, fineness (weight per inch), width, strength, rigidity, convolutions or natural twist in the fibre, and clinging power.

In my paper of 1926 I pointed out that we may formulate an equation for determining the highest standard warp counts, C, in terms of the fibre-properties, as follows :—

$$C = f(x, y, z, \ldots).$$

This is merely the symbolic method of specifying that the highest standard warp counts for which a cotton is suitable is a function of its fibre-length x, fibre-weight per inch y, fibre-strength z, and so on. During the past five years investigation has been proceeding at the Technological Laboratory, and we have now obtained a mass of data which has enabled us to advance some way upon the road. I said in my previous paper that little or nothing is known about the function of the fibre-properties in which the highest standard warp counts may be expressed. This remains true at the present time. In order to approach the subject we have made the preliminary assumption that this function is of the simplest possible kind, *viz.*, a linear one with certain constants. In order to evaluate these constants we have had to employ a statistical method. Now it is evident that hitherto the difficulty in using the statistical method has been the absence of an adequate supply of data ; our first object, therefore, has been to fill this gap. What is particularly wanted in order to solve many of the problems of cotton technology is a knowledge of the facts ; our first business has there-

fore been to obtain the facts, though it is well to remember here that our "facts" are subject to personal errors, experimental errors and most important of all sampling errors, which have formed the subject of some of our most exhaustive research work. So far we have obtained the "facts" for 95 samples of cotton; we have not only subjected these to the detailed spinning test, including the subsequent testing of the spun yarns, but we have also made many thousands of tests on these cottons for the various fibre-properties, *viz.*, length, weight per inch, strength, ribbon width, convolutions, and rigidity; and, in 45 cases, the clinging-power as well. The mean values for these different fibre-properties have now been ascertained for the 95 samples of Series I and the 45 samples of series II, and have necessitated the making of some half million individual fibre and yarn tests. The equation to the line of best fit has been found showing the relation between the finest counts and the fibre-properties. This process has involved much statistical work, as we have had to use the method of partial correlation in order to obtain this equation, about which I may now say a few words in explanation of the method.

We use the term "correlation" to indicate that there is some association between two or more quantities or qualities; the "correlation co-efficient" is a mathematical index expressive of the degree of association. All correlation co-efficients lie within the range from +1 to —1; a correlation co-efficient of +1 indicates that under all conditions there is exact proportionality between the mean values of the quantities concerned; where there is no relation of any kind between the two quantities, then the correlation co-efficient has the value 0; the correlation co-efficient has a negative value when an increase in the mean value of one quantity is associated with a decrease in the mean value of the other. We have determined the simple correlation co-efficients between the highest standard warp counts and each of the fibre-properties separately, with the following results for the 95 samples:

Length	+0·87
Weight per inch	—0·80
Strength	—0·33
Strength per unit weight per inch	+0·59
Width	—0·69
Convolutions	+0·46
Rigidity	—0·67
Clinging power (45 samples)	—0·67

In the case of fibre-length and fibre-weight per inch we have also determined the correlation between each of these properties and the highest standard warp counts for 274 other (non-standard) samples, giving the following correlations: between counts and fibre-length, +0·86; between counts and fibre-weight, —0·71.

Taking the standards and non-standards together, we have the equivalent of 460 non-standard samples, giving the correlations between counts and fibre-length, +0·87, and between counts and fibre-weight, —0·75. All these correlations are simple correlations. From them we have deduced the equations of the lines of the best fit showing the highest standard warp counts for the values of each fibre-property alone.* We have then applied these equations to the original data, using them as predicting equations and ascertaining the order of accuracy of the prediction of spinning value from each single property. For the 95 samples we find that length gives much the best results, and in practically 50 per cent. of the cases the divergence between the actual and predicted counts does not differ by more than 10 per cent. of the actual value ; in 67 per cent. of the cases the difference does not exceed 20 per cent. For fibre-weight per inch 32 per cent. of the differences do not exceed 10 per cent., and 50 per cent. do not exceed 20 per cent. The results for other properties are not so good.

Now from among the mean values of the test-results for the 95 samples we can select examples of cottons which have the same mean value for a given fibre-property and yet have widely different highest standard warp counts. Hence, even though the single property of fibre-length gives comparatively good results, it is obviously undesirable to restrict our prediction formula to one property alone. The derivation of a formula to take into account more than one fibre-property is a somewhat laborious proceeding, and depends on the calculation of the "partial correlation co-efficients". We have seen that the highest counts are strongly positively correlated with fibre-length and strongly negatively correlated with fibre-weight per inch, *i.e.*, that for the highest counts of yarn we need long and fine cottons. Now if it happened that a long cotton was invariably a fine one, with an exact quantitative relation between the mean values for these properties, length would be perfectly negatively correlated with fibre-weight per inch, and the correlation co-efficient between counts and length would have exactly the same value as, but an opposite sign to, that between the counts and fibre-weight per inch. In this case it is evident that the determination of fibre-weight in addition to fibre-length would bring us no nearer to the solution of our problem. But if fibre-length and fibre-weight are not perfectly correlated, it is possible that the difference from perfect correlation may be responsible for the imperfect correlation between the counts and either fibre-length or fibre-weight per inch. Evidently, therefore, we must take into consideration the possibility of correlation between the different fibre-properties themselves. This is done by formu-

* Typical equations, based on the 95 samples, are :—
For fibre-length, l : $C = 108{\cdot}2\,l - 65{\cdot}7$.
For fibre-weight per inch, w : $C = 57{\cdot}2 - 164{\cdot}1\,w$.

lating an equation in which each independent variable—representing the mean value of a fibre-property—has attached to it a constant which gives expression to the part played by that particular property independent of all the other fibre-properties. As previously indicated, the statistical method of doing this is by means of the partial correlation co-efficients. Such partial correlation co-efficients have been worked out for each pair of properties separately, regarding first one of the other properties as constant and then successively 2, 3 or more, until finally the partial correlation co-efficients have been obtained for each pair of properties independently of all the other properties measured. In this investigation it has been necessary to calculate altogether, 548 correlation co-efficients, 212 for Series I (95 samples, 7 properties) and 336 for Series II (45 samples, 8 properties), distributed as follows :—

Correlation co-efficients of	*Series I.*	*Series II.*
Zero order	21	28
First order (one other property constant)	60	63
Second order (two other properties constant)	51	75
Third order (three other properties constant)	42	70
Fourth order (four other properties constant)	27	54
Fifth order (five other properties constant)	11	33
Sixth order (six other properties constant)	..	13

The most interesting " equations of best fit " finally obtained in this work when more than one property is taken into consideration are as follows :—

For counts in terms of

length l and weight per inch w : (95 samples),

$C=75{\cdot}4\,l-79{\cdot}5\,w-22{\cdot}8$;

length l, weight per inch w, and strength s : (95 samples),

$C=72{\cdot}5\,l-93{\cdot}3\,w+26{\cdot}7\,s-21{\cdot}8$;

length l, weight per inch w, diameter d, strength s, convolutions or twist t, and rigidity r : (95 samples),

$C=71{\cdot}6\,l-70{\cdot}8\,w-20{\cdot}8\,d+17{\cdot}9\,s+0{\cdot}037\,t+4{\cdot}4\,r-14{\cdot}1$;

length l, weight per inch w, diameter d, strength s, convolutions or twist t, rigidity r, and clinging power p : (45 samples),

$C=42{\cdot}7\,l-66{\cdot}4\,w-49{\cdot}3\,d-18{\cdot}7\,s+0{\cdot}0277\,t+21{\cdot}8\,r-26{\cdot}2\,p+39{\cdot}5$.

It may be observed that when all the fibre-properties which have been measured are taken into consideration, there is usually fairly close correspondence between the predicted values and the actual values of the highest standard warp counts. In practically all cases the difference is no more than 20 per cent. on either side of the actual value, and in 50 per cent. of the cases the difference is not more than 10 per cent. on either side of the actual value, so that it appears that our extensive physical measurements would allow us to predict the spinning value with greater accuracy than the cotton grader can do with certainty. The mathematical

index for expressing the degree of association between the single property of highest standard warp counts and all the fibre-properties together, is known as the multiple correlation co-efficient; this is as high as 0·93 for our 95 samples, showing that the highest standard counts are calculable from the fibre-properties with a fairly close degree of approximation. At the same time, the correlation co-efficient for highest standard warp counts and length alone is 0·87, so that the very laborious testing and subsequent calculations for all the other fibre-properties have only lifted up the value of the correlation co-efficient by 0·06.

It is remarkable that the correlation between fibre-length and highest standard counts is considerably higher than between the fibre-weight and the highest standard counts. It follows therefore that if we are dealing with a wide range of cottons, a judgment of their performance will be more accurate if we base it solely on fibre-length than if we base it solely on fibre-weight; and although it may be true, as Balls maintains, that the long cottons spin better than the short ones chiefly because the long cottons are also the fine ones, yet as a single index of quality the fibre-length stands superior to the fibre-weight per inch and so justifies the attribution of so much importance to it by the cotton grader.

We have seen that there is no complete relation between the highest standard warp counts and the various fibre-properties, taken separately or conjointly, and that some other factors must therefore either upset or mask the influence of the particular properties that have been measured. To what causes may we ascribe the anomalies among our results? Firstly, it is of course just possible that some important fibre-property has been overlooked, but before accepting this solution we may review certain other possibilities. In the second place, we have assumed that a linear relation exists between the highest standard warp counts and the fibre-properties. Seeing that the regression curves (lines of best fit) for the properties of strength and rigidity alone are decidedly non-linear, we cannot expect linearity in the case of the multiple correlation. Thirdly, and probably more important, is the fact that the values used for calculating the correlation co-efficients are merely average values, and even if two cottons have the same average values for all the different fibre-properties, it does not by any means follow that the variation of any particular property, is the same for the two cottons, and consequently, that the property itself is really the same for both. A fourth consideration of the highest importance must also be borne in mind, *viz.*, that the strength of a cotton fibre is, practically speaking, a single point phenomenon, and the doubling together of a number of fibres to form a yarn makes it possible to take advantage of the strength of the stronger parts of the fibre—indeed, most parts of the fibre are at least 3 or 4 times as strong as the one or two weakest points. Thus the regularity of strength along a cotton fibre may play a

large part in conferring strength or weakness upon the yarn made from that cotton, the yarn being comparatively strong or weak according as the strength of the stronger parts of the fibre exceeds that of the weakest part to a greater or less extent. A fifth consideration is the dispersion of the substance of the fibre: although two fibres may have the same fibre-weight per inch, yet one may have a large diameter with a thin wall, and the other a small diameter with a comparatively thick wall, so that the former on collapse will give a more ribbon-like structure than the latter: and it is not to be expected that both will give the same results in spinning.

Here then are a few grounds on which we may yet possibly explain our anomalies. We have made considerable progress in an investigation, still proceeding, of the cases where our prediction formula is least successful, and we have already obtained some very promising results. The subject is of course a fascinating one, by virtue of the very difficulties with which it bristles. But when all is said and done, we must pay our tribute to the cotton grader, who, single-handed and using no apparatus but his own physical senses, is able by his empirical method to make in two minutes a valuation of a cotton with usually a fairly high degree of accuracy, whereas the *ad hoc* spinning and yarn testing on the one hand, and the scientific fibre-testing on the other, each require about two days' work for the determination of the quality of a single sample, and they each employ an expensive equipment and a numerous staff. Hence it is unlikely that either the spinning test or the scientific fibre-tests will displace the grader's valuation in commercial practice. But where the highest accuracy is required, as in deciding between a series of a cotton breeder's selections of a similar kind, the spinning test must still remain the ultimate court of arbitrament, though there is now every hope that our research work on the fibre-properties will eventually allow us to offer much more trustworthy advice than the cotton grader can do at those early stages in plant breeding when the quantity of cotton lint produced is all too small for a satisfactory spinning test.

OSMOTIC AND SUCTION PRESSURES OF THE RICE PLANT (*ORYZA SATIVA* L.).

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The rice plant is one of the most important of the economic plants in India, and is very widely cultivated as a crop plant in different countries. The plant has been the subject of scientific study for a very long time past, and agriculturists have tried to determine the best conditions for the growth of the plant with a view to increase the crop yield per unit area. A large amount of work is done both in India and abroad on the cultivation of the rice plant from different points of view, and a good summary of that work is given by Copeland [1924] in his book on rice.

The work on the physiology of rice is both scanty and scattered. Few observations have been made on its respiration. Bailey and Gurjar [1920] in their studies on the respiration of cereal plants and grains determined the respiration of paddy and milled rice, and the results indicate a relationship between the amount of CO_2 evolved and the percentage of total moisture. The amount of increase of respiration with an increase of moisture varied with different species.

Amongst the soil factors, the water content of the soil is the most important in the case of the rice plant. As it is a semi-aquatic plant with its roots standing in water, the lowland rice is generally grown in heavy soil where the water does not percolate but is retained by the soil. This habit of rice is responsible for many peculiarities in its growth. The immersed condition of the roots has opened the question of their respiration. Harrison and others [1914] have put forward a view to explain how the oxygen concentration of water in the soil is increased by the decomposition of various gases, which appear as decomposition products of organic matter. The surface of the soil in immediate contact with water is covered with a film of soil algæ, which utilize the soil gases such as methane and hydrogen, and produce oxygen. The film contains certain bacteria which oxidise CH_4 to CO_2, and CO_2 is decomposed by green algæ such as diatoms in the presence of sunlight, and oxygen is produced. Green manuring helps in the production of methane, and this was actually found to be the case.

The study of the rice plant made by Joshi and Gadkari [1923] at Karjat, Bombay Presidency, is done mainly from the point of view of an agriculturist, and they have been able to find out the best methods for the cultivation of rice and of

manuring the rice fields at the proper times. But a point is reached in the study of the rice plant where a proper study of its internal mechanism may lead to useful results from an economic point of view. As it is, the knowledge obtained is more or less empirical, and unless we have some information about the internal physiological activity of the plants, we are unable to correlate the effect of a particular treatment produced on the growth or on the yield of the plant. This is true not only of rice, but of all economic plants. Rice is selected for the purposes of this investigation, as it is a plant which is widely cultivated in the Bombay Presidency, and the climate of Bombay is suitable for its growth, and as much reliance cannot be placed on results obtained from the physiological studies of a plant if it is not grown under identical conditions of climate and soil.

We have to thank Mr. Gadkari of the Rice Research Station, Karjat, for his kind help in sending us fresh seeds and seedlings for transplantations.

Special beds were prepared for cultivating rice in the garden of the Royal Institute of Science, and arrangements were made for impounding water in the beds and watering during the periods of drought. The seedlings of variety No. 42 commonly grown in the Kolaba district were obtained from the Rice Research Station at Karjat, and immediately transplanted in bunches of four, at a distance of eight inches as recommended by Joshi and Gadkari [1923].

It is intended to make a detailed study of the rice plant, including the different phases of its nutrition, growth and reproduction which is likely to extend over a period of seven years, as the plant is available for study for the period of four months only in the year, and that involves loss of time. This investigation includes one aspect of rice physiology, *viz.*, the osmotic pressure and the suction pressure of the roots and leaves during the life period of the rice plant.

In a vegetable cell which is enclosed in an elastic membrane, the cell wall, there exist two pressures which are exerted in opposite directions. Firstly, there is the osmotic pressure exerted by the cell sap in the vacuole, which is also known as the turgor pressure, the turgor concentration of the cell sap, etc. The term osmotic pressure is only applicable when the cell is surrounded by another liquid or by pure water, and this quantity is denoted by the terms " osmotic value " by Ursprung and Blum [1916, 1]. Secondly, the cell wall is elastic, and when it is stretched beyond its normal volume on account of the absorption of water by osmosis, it exerts an opposite pressure to the hydrostatic pressure exerted against it by the liquid in the cell. The pressure exerted by the cell wall against the cell contents is known as the wall pressure, and that exerted by the cell contents against the cell wall is termed turgor pressure.

The amount of water that passes into a cell depends upon the difference between the osmotic pressure of the external medium and the osmotic pressure

of the cell contents *minus* the inwardly directed wall pressure. This quantity is termed suction force by Ursprung and Blum [1916, 2], and indicates the net pressure with which the water passes into the tissues. Stiles [1924] calls it a net suction pressure or a full suction pressure according as the external medium is a solution or pure water. Molz [1926] uses the term suction force of the cell content for the osmotic value of a cell, and retains the term suction force of the cell for the pressure with which water passes into the cell. So the suction pressure or the suction force of a cell is equal to the osmotic value of the cell contents *minus* the wall pressure when the surrounding medium is water. The measurement of the suction pressure of the cell is, therefore, a true indicator of the force with which the water passes inside.

The measurement of the suction and osmotic pressures of the plant cells have been made by various workers before, and they have been correlated to some factor such as the soil, plant organs, the different varieties of the species, or to the other life processes of plants.

The suction force of different varieties of the American and Egyptian cotton was determined by Taschdjean [1928] who found that the suction force was directly proportional to the germinating capacity of the seeds, the length of the staple and the harvest. The osmotic and the suction pressures of cultivated plants such as beetroots, lucerne and clovers were determined by Eibl [1927, 1, 2]. He found that indigenous varieties of other plants had higher osmotic and suction values than the imported ones. He also worked on the suction pressure of cereals of different places, and he found that the osmotic pressure of a species was greater, the shorter the vegetative period of that species.

The observations of Eibl [1927, 1, 2] were extended on vegetables and economic plants by Oppenheimer [1927] who discovered that the suction pressure was related to the period of germination as the product of both was constant.

Kandija [1926] found that the daily fluctuations of the suction presssure in *Bellis perennis* were related to the daily fluctuations in the rate of transpiration. The daily periodicity was also influenced by changes in the external factors such as humidity, temperature and light. Blum [1926] also found in some plants during the vegetative period, daily periodical fluctuations in suction pressure which were related to the distribution of rain and dry weather. He also found that the plants growing without manures show higher suction pressures than manured plants. Demdidenko [1926] has, however, shown that the osmotic pressure of the cell sap depends upon the osmotic pressure of the salt solution outside, and an increase in the osmotic pressure of the solutions in the soil increases the osmotic pressure of the cell sap.

Similar variation of the suction pressure in the roots of plants were noticed by Litwinowo [1926]. The variations in the osmotic pressure of the culture solution and the suction force were found to be proportional to the increasing concentration of the culture solution.

For the purposes of this investigation, it is clear that the determination of the osmotic value and the net suction pressure of the different organs and tissues of the rice plant for the whole season would be of great interest as the absorption of water of nutrients would depend on the suction force of the root stems and leaves of the plant. They are also likely to throw light upon the period when the absorptive activities are at their highest pitch.

Various methods are employed for determining the osmotic pressure. The simplest one is the plasmolytic method of De Vries [1844, 2] which has been modified by Höfler [1918]. For the purpose of this investigation, the plasmolytic method of De Vries [1844, 2] was adopted, as a large number of determinations had to be finished in one day and the results obtained by both methods show small differences.

TABLE 1.

Measurement of osmotic pressure by the plasmolytic and plasmometric methods.

	Plasmolytic method	Plasmometric method	Difference
	Atms.	Atms.	Atms.
Leaf sheath 1	11·66	12·08	+0·42
Leaf sheath 2	11·66	11·3	—0·36
Leaf apex 1	18·49	17·7	—0·79
Leaf apex 2	18·49	18·3	—0·19
Spike 1	14·35	13·2	—1·15
Spike 2	14·35	14·6	+0·25

In the plasmolytic method which was used by De Vries [1844] for determining isotonic co-efficients, the known solution of sugar which just brings out plasmolysis is regarded as isotonic with the cell sap and has the same osmotic pressure. Sucrose is generally used for such determinations as it penetrates into the plant cells very slowly and consequently does not interfere with the determination on account of the lack of endosmosis. The osmotic pressure values in atmospheres of sugar solutions of different concentrations have been determined by Morse [1914]. The

tables of these determinations given by Ursprung and Blum [1916, 1] and Ursprung and Hayoz [1922] are made use of in this investigation.

Cane sugar solutions of different concentrations from 0·05 N. to 1 N. were prepared in measuring flasks and placed in small glass bottles of 10 to 25 c. c. and closed with glass stoppers. The sections of a plant organ were placed in different solutions for 30 to 40 minutes according to their nature. They were then examined rapidly under a microscope for plasmolysis, and the solution in which half of the cells of a tissue showed incipient plasmolysis was taken as isotonic with the cell contents.

The rice seedlings were obtained on July 14th, 1927, and were transplanted on the same day. They were watered daily.

The determination of the osmotic pressure was made at different points on the plant surface to get an idea of the osmotic pressure existing in different organs of the plant body. Young roots which are probably the main absorbing organs were selected for determining the osmotic pressure, and the pressures of the tissue below the tip and the tissue at the base were determined. The observation of plasmolysis was not restricted to any one position, but a number of sections were kept in the solution and the solution in which most of the cells in all the sections showed incipient plasmolysis was taken as isotonic with the cell contents of the tissue at the tip. The variations of osmotic pressure in different sections were of a minor order, so that the Tables given below represent almost correctly the osmotic pressures, in the rootlets of the plant on that particular day when measurement was made.

The measurement of the osmotic pressure was also made towards the base of the rootlets. The cortical tissue was taken for the measurement of the osmotic pressure, and the same procedure was followed.

In the case of the leaves, the osmotic pressure of the leaf sheath and the lamina near the apex were examined. Sections were cut parallel to the veins, and the mesophyll cells were used for determining plasmolysis.

Some sources of error are introduced in the determination of the osmotic pressure by the plasmolytic method. A long immersion of cells in a solution brings about a change in the concentration of the cell sap on account of exosmosis. This could be avoided by shortening the period of immersion.

The osmotic pressure was measured at different hours of the day, but the variations were found to be slight. Nevertheless, all the measurements were made at the same hour of the day, to avoid errors arising from daily variations in the osmotic and suction pressures.

The osmotic pressures that are given below are the pressures in the cells at the time of plasmolysis.

TABLE II.

Measurements of the osmotic pressure in the roots and leaves of the rice plant during the whole season.

Date	O. P. Root apex	O. P. Root base	O. P. Leaf sheath	O. P. Leaf apex
	Atms.	Atms.	Atms.	Atms.
July 28, 1927	6·48	..	10·38	12·96
August 3, 1927	7·65	8·97	12·97	17·12
August 11, 1927	8·98	11·64	17·1	17·1
August 15, 1927	7·665	8·99	14·32	18·47
August 22, 1927	11·645	12·969	19·89	22·54
August 26, 1927	12·975	14·34	18·475	21·35
August 30, 1927	14·349	15·7	17·12	24·22
September 2, 1927 . . .	12·965	15·68	17·09	21·35
September 6, 1927 . . .	10·323	14·33	18·45	21·37
September 10, 1927 . . .	7·647	12·97	18·49	18·5
September 13, 1927 . .	7·55	12·99	15·75	18·5
September 19, 1927 . . .	6·27	10·253	14·35	18·5
September 20, 1927 . . .	6·27	10·253	14·35	17·12
September 23, 1927 . . .	5·04	7·668	12·97	19·37
September 26, 1927 . . .	7·64	8·97	17·1	19·93
September 30, 1927 . . .	6·34	8·97	15·76	19·48
October 4, 1927	6·34	8·97	15·7	19·48
October 7, 1927	5·04	7·64	12·97	18·49
October 12, 1927	5·02	7·64	12·98	18·51
October 15, 1927	..	..	11·63	18·52
October 10, 1927	..	..	10·27	15·73
October 24, 1927 . . .	..	..	10·25	15·74
October 28, 1927	..	..	10·26	14·51
November 1, 1927 . . .	..	..	10·26	12·99
November 7, 1927 . . .	..	..	10·25	12·99

After the 12th October it was not possible to determine the osmotic pressure of the roots as the roots were almost dead and hence no measurements could be made.

On studying the figures it at once becomes evident that the values of osmotic pressure vary in the roots. The osmotic pressure in the cells near the apex is less than in the cells towards the base. The osmotic pressure in the roots shows a periodicity. It increases after the plants are transplanted, reaches a maximum towards the end of August, and then begins to fall gradually. There was a small rise in the osmotic pressure on the 26th September, which was very probably due to the effect of manuring on the previous day with ammonium sulphate when the osmotic pressure rose from 5 atms. to 7·64 atms., but it was only a temporary rise as it again began to decline. It practically remained constant towards the end of the vegetative period when the roots showed signs of death.

There is a small discrepancy in the result on the 15th August when there is a fall in the osmotic pressure. It is very likely that this discrepancy is due to some experimental error.

In the case of the leaves, the osmotic pressure of the cells follow approximately the same rate, though the results are not as regular as they are in the case of the roots. It also increases slowly, fluctuates around the maximum point for a longer time than in the case of the roots, and then begins to decline slowly. There is a rise in osmotic pressure on the 26th September after manuring, and then there is a steady decrease. The fall in the osmotic pressure in the leaf sheaths is steady from the 30th September, and remains practically constant up to the end. The same course is followed in the leaves towards the apex, except the result on November 2, 1927, which shows a fall of osmotic pressure by $1\frac{1}{2}$ atms.

The irregularities in the results may be due to local variations of osmotic pressures, as it is difficult to take identical parts of leaves and roots for each day's determination.

On studying the values of osmotic pressure in the root and the leaf for each day, it is seen that the value of osmotic pressure increases from the base of the root to the apices of the leaves. This is true without exception as is seen from the results.

The fall in the osmotic pressure begins :—

In root apex from 30th August,

In root base from 3rd September,

In leaf sheath from 13th September, and

In leaf apex from 20th September.

Ursprung and Blum [1916, 2, 3, 1923] in the beginning made use of the volume of the cell undergoing no change in a fluid of known osmotic value in deter-

mining the suction pressure. But as it was difficult to measure the volume accurately, the surface measurements of the cell were resorted to. Later, they developed a simple method in which an average suction pressure of a whole strip of tissue could be measured. The same method was employed by Molz [1926] in studying the suction pressure of a large number of species.

As the above method is found very suitable for making daily determinations of the suction pressure, it is used in this investigation.

A rice plant is carefully uprooted and small pieces of the roots are cut off and measured in paraffin oil. The paraffin oil is removed by means of filter papers, and the strips are placed in cane sugar solutions of graded strengths. The suction pressure is measured at two places—just below the apex and between the middle portion and the base. The pieces of the root apex are split into two as the apical region is very thin. At the root base the cortical and vascular tissues are separated, and separate measurements are made of their suction pressures. The apical and cortical tissue strips are kept for $\frac{1}{2}$ hour and the vascular for 45 minutes in the sugar solutions. They are then measured, and the osmotic pressure of the solution in which there is no increase or decrease in the original length of the strip, corresponds to the suction pressure of the strip of the tissue. All the necessary precautions against errors in measurements arising from parallax, stretching of the folds of the tissue under pressure of the cover slip, etc., are taken. The root tips are measured in the direction of the maximum stretching. The following table gives the determinations of the suction pressures of the tissues of the roots and leaves.

TABLE III.

The suction pressure in the roots and leaves of the rice plant during the whole season, 1928.

Date.	S. P. Near Root apex	S. P. Near Root base		S. P. Near Leaf sheath	S. P. Near Leaf apex
	Atms.	Atms.		Atms.	Atms.
July 23, 1928	2·456	3·85		..	..
July 25, 1928	2·19	4·43		7·67	10·29
July 27, 1928	4·4	6·37		9·52	10·29
July 30, 1928	4·41	7·13		7·6	8·99
July 31, 1928	5·07	6·37		7·6	8·99
August 2, 1928	3·85	5·55		7·1	10·27
		Vas. Tissue	Cort. T.		
August 4, 1928	4·43	5·07	5·07	7·67	12·97
August 8, 1928	4·41	5·1	4·1	7·67	12·97
August 10, 1928	4·41	5·1	4·1	7·32	12·24
August 13, 1928	4·45	6·35	5·02	7·2	11·64
August 17, 1928	5·1	7·67	5·1	7·2	13·45
August 20, 1928	5·1	8·25	5·35	7·13	14·23
August 27, 1928	5·21	7·7	6·41	7·7	13·45
September 4, 1928	5·22	7·4	8·23	8·96	15·3

The suction pressure in the roots and leaves of the rice plant during the whole season, 1928—contd.

Date	S. P. Near Root apex	S. P. Near Root base		S. P. Near Leaf sheath.	S. P. Near Leaf apex
		Vas. Tissue.	Cort. T.		
	Atms.	Atms.	Atms.	Atms.	Atms.
September 6, 1928 . .	5·22	7·65	8·21	8·21	15·3
September 10, 1928 . .	4·4	7·41	8·24	8·96	15·7
September 15, 1928 . .	3·7	7·4	8·21	8·95	12·97
September 18, 1928 . .	4·4	7·41	7·68	8·22	14·33
September 21, 1928 . .	5·3	9·82	10·24	10·61	18·47
September 29, 1928 . .	4·45	7·43	10·27	9·83	15·64
October 5, 1928 . . .	4·15	9·53	10·27	9·53	14·3
October 9, 1928 . . .	3·81	8·2	8·97	9·53	14·98
October 11, 1928 . . .	3·02	8·22	10·78	10·28	17·15
October 13, 1928 . . .	3·02	8·21	10·79	10·28	17·15
October 17, 1928 . . .	4·15	9·23	10·79	11·62	15·72
October 20, 1928 . . .	3·81	8·97	11·64	11·64	17·14
October 23, 1928 . . .	3·81	8·97	11·62	11·62	17·13
October 26, 1928 . . .	..	11·64	12·22	14·35	17·8

Bed I was manured on September 21st.

The suction pressure near the apical region of the root rises for a week after transplantation, and then fluctuates between 4 and 5·5 atmospheres. The variations in the suction pressure are very little in August up to the middle of September. Slight variations may be due to soil conditions. It is certain, that the suction pressure in different individuals may vary within narrow limits, and, since these determinations are not made on the same plant every time but on different individuals, these variations in the results are likely to occur. There is a slight increase in the suction pressure after the plot is manured with three ozs. of ammonium sulphate, but the increase is not maintained, and it again falls to less than four atms.

The average suction pressure in the cortical tissue is less than the average suction pressure in the vascular tissue in the beginning, but later on it becomes higher in the cortical tissue. Generally it is known that the suction force increases in roots from the epidermis towards the vascular tissue in each successive row of cortical cells, and it falls in the endodermis and in the wood parenchyma, while in the rice plant, the suction pressure in the vascular tissue is higher than the cortical tissue in the beginning, and though it becomes less later on, the difference between the two is not very great. But in this case what is measured is the average suction pressure for the cortex. The vascular tissue includes the pith and phloem regions and not the wood cells only, and hence the value of the suction pressure is higher than that of the cortical tissue, or is nearly equal to that

of the latter. The values of the suction pressure in these two tissues go up after manuring, and they remain fairly constant up to the end.

Measurements of the suction pressure in the leaves of the rice plant were made simultaneously (Table III). In the case of the leaves, sections were cut parallel to the veins in all cases as there will be a difference in the readings if the sections are cut at right angles to the veins of the leaves.

There is a regular rise in the suction pressure in the leaves. It is not so uniform as in the case of the roots. It fluctuates between 7 atms. and 8 atms. in the leaf sheath in July and August, and in the lamina it varies from 10 to 13 atms. in the same month. In September there is a slight rise in the suction pressure but after manuring it goes up to 10·62 atms. in the leaf sheath and 18 atms. in the lamina. But that rise is not maintained except towards the end of October when there is again a rise in the suction pressure which will be explained later on when the relations between the osmotic pressure and suction pressure are discussed.

Bed I was manured with ammonium sulphate on the 20th September, but Bed II was manured on September 5th, to study the effect on suction pressure if manured a fortnight before. At the same time the results obtained with Bed II may be compared to those of Bed I, to see if there are any differences in the values in the suction pressure of plants grown in the two separate beds.

TABLE IV.

The suction pressure in the rice plants—Bed II. (Manured with ammonium sulphate on August 5, 1928.)

Date	Root apex	Root base cortex	Leaf sheath	Leaf apex
	Atms.	Atms.	Atms.	Atms.
September 7, 1928 . . .	6·15	8·96	8·9	17·17
September 11, 1928 . . .	5·14	8·97	9·8	16·4
September 14, 1928 . . .	4·4	8·96	9·81	15·68
September 19, 1928 . . .	4·42	7·68	9·81	14·32
September 26, 1928 . . .	4·4	10·29	10·29	14·3
October 4, 1928	3·67	8·97	10·26	15·35
October 8, 1928	4·17	10·8	10·8	14·37
October 10, 1928 . . .	5·01	10·79	10·28	15·71
October 12, 1928 . . .	4·15	10·79	10·28	15·72
October 16, 1928 . . .	4·15	11·64	10·28	15·73
October 20, 1928 . . .	5·01	11·64	10·82	16·42
October 23, 1928 . . .	5·01	11·62	10·8	16·44
October 25, 1928 . . .	..	11·64	14·37	17·82

The results show the same regularity as in Bed I, and towards the end of October the readings agree very closely with those of Bed I.

The measurements of the suction pressure in the case of the spike were made side by side, and it was noticed that the suction pressure fluctuated between 10·2 atms. and 15·7 atms. In all cases the suction pressure steadily increased.

TABLE V.

The suction pressure in the spike in Beds I, II, III, IV.

Date	Bed I	Bed II	Bed III	Bed IV
	Atms.	Atms.	Atms.	Atms.
October, 8th	10·8	10·8	..	10·8
„ 9th	10·27	..	10·27	..
„ 10th	..	11·64	..	11·64
„ 11th	..	..	10·8	..
„ 12th	..	10·63	..	11·63
„ 13th	..	..	10·82	..
„ 14th	..	..	..	13·01
„ 16th	..	11·62	..	..
„ 17th	12·22	..	..	..
„ 18th	..	..	12·22	..
„ 19th	..	..	..	13 02
„ 20th	12·22	14·37	..	..
„ 22nd	..	..	13·03	13·03
„ 23rd	12·22	14·37	..	..
„ 24th	..	..	13·2	..
„ 25th	..	14·98	..	..
„ 26th	15·73	..	..	..

On comparing the osmotic pressures in the four regions of the rice plant with the suction pressures in the same region of the root and the leaf, it is noticed that at the end of the vegetative period the osmotic pressure tends to become equal to the suction pressure. This similarity was noticed after the results on suction pressure were obtained at the end of the rice season in 1928. The results of osmotic pressure obtained in the rice season of 1927 cannot be strictly comparable with the results of the suction pressure obtained in 1928, but taking the uniform conditions under which the rice plants were grown in both years, the same strain No. 12 of the rice plant being used in both the seasons and the seedlings obtained from the

same place for transplantation, a fair comparison could be made. As the measurements of the osmotic and suction pressures are not made in the same season, it introduces an irregularity that the suction pressure is higher than the osmotic pressure during the last days of October, as the suction pressure should be equal to the osmotic pressure when the wall pressure and turgor pressure are at their lowest value, *i e.*, equal to zero.

To test the view that during the active stage of the plant the suction force is less than the osmotic pressure, and towards the end of the season the suction pressure becomes equal to the osmotic pressure, the following two sets of measurements were made in November. Table VI gives the measurements of the suction pressure and the osmotic pressure in the various organs of the plant during the beginning of the vegetative activity. The determinations of both the values were made with the material from the same plants.

TABLE VI.

Measurements of suction and osmotic pressures in the rice plant at the beginning of vegetative activity.

	Osmotic pressure	Suction pressure	Difference
	Atms.	Atms.	Atms.
Root apex	8·97	2·56	6·41
Root base	13·03	7·5	5·53
Leaf sheath	14·37	8·97	5·4
Leaf apex	17·13	10·24	6·89

A number of determinations were made of the osmotic and the suction pressures in the leaves of the rice plant towards the end of the season. The measurements of the osmotic pressure and the suction pressure were made side by side in the same leaf, on the same day and at the same time. Similar measurements were also made for the spike.

TABLE VII.

Measurements of osmotic and suction pressures of the rice plant at the end of the vegetative activity.

	Osmotic pressure	Suction pressure
	Atms.	Atms.
Leaf apex	18·49	17·8
Leaf apex	17·8	17·8
Leaf apex	17·13	17·13
Spike	14·35	14·35
Spike	14·98	14·35
Spike	14·35	14·35

The above results conclusively show that the suction pressure is less than the osmotic pressure in the beginning, and the osmotic pressure of the tissue becomes equal to the suction pressure at the end of the vegetative season and remains so till the plants are dead. This fact is of importance as it clearly indicates that the turgor pressure in the cells goes on diminishing as the plant gets older, and ultimately falls to zero in October.

The above observations of osmotic and suction pressures of the rice plant were made in two rice seasons of 1927 and 1928 respectively, and it was thought necessary to measure the osmotic and suction pressures of the plant together in the same season, on the same or at least on alternate days. The results are given below in Tables VIII and IX.

TABLE VIII.

Osmotic pressure, 1929.

Date	Root apex	Root base	Leaf sheath	Leaf apex	Spike
	Atms.	Atms.	Atms.	Atms.	Atms.
July 19, 1929	5·6	7·65	8·97	14·25	..
July 22, 1929	6·23	7·65	8·97	17·12	..
July 24, 1929	6·23	7·65	10·22	17·12	..
July 26, 1929	6·23	8·97	10·22	17·12	..
July 30, 1929	7·65	8·97	10·22	17·82	..
August 3, 1929	7·65	8·97	10·22	17·82	..
August 10, 1929	8·2	10·25	11·6	20·01	..
August 13, 1929	8·2	10·25	11·6	20·01	..
August 20, 1929	8·2	10·25	12·92	22·54	..
August 24, 1929	8·2	10·25	12·92	22·54	..
September 3, 1929	10·8	14·32	15·8	22·54	..
September 10, 1929	11·6	14·32	17·09	23·12	..
September 18, 1929	8·92	12·97	18·45	22·54	..
September 20, 1929	7·65	10·25	17·09	24·22	..

Osmotic pressure, 1929—contd.

Date	Root apex	Root base	Leaf sheath	Leaf apex	Spike
	Atms.	Atms.	Atms.	Atms.	Atms.
October 2, 1929	7·65	10·25	15·8	22·45	..
October 4, 1929	7·65	10·25	15·8	22·45	..
October 9, 1929	6·34	9·53	14·32	21·37	14·51
October 14, 1929	7·65	10·25	14·37	21·37	15·75
October 18, 1929	7·68	10·25	12·97	19·93	14·51
October 23, 1929	..	10·25	11·6	19·93	12·99
October 28, 1929	..	10·25	11·6	19·93	12·99
November 7, 1929	5·01	7·6	11·6	17·48	..

TABLE IX.

Suction pressure, 1929.

Date	Root apex	Root base	Root cort	Leaf sheath	Leaf apex	Spike
	Atms.	Atms.	Atms.	Atms.	Atms.	Atms.
July 20, 1929	..	5·1		7·65	10·29	..
July 23, 1929	2·45	5·6	7·4	7·65	10·23	..
July 25, 1929	..	6·22	7·4	7·65	10·29	..
July 27, 1929	3·01	6·22	7·4	7·65	10·6	..
July 30, 1929	3·01	6·22	7·4	8·2	11·6	..
August 3, 1929	4·4	6·2	7·4	8·2	11·6	..
August 13, 1929	4·4	7·61	8·2	8·2	12·8	..
August 19, 1929	5·62	7·65		8·2	13·33	..
August 23, 1929	6·21	6·8	7·65	8·2	13·45	..
September 4, 1929	5·63	6·8	8·82	10·25	13·45	..
September 14, 1929	6·21	7·6	8·82	10·25	14·4	..
September 19, 1929	5·62	8·25	10·25	11·6	15·8	..
September 24, 1929	5·22	7·6	9·53	10·25	15·8	..
October 3, 1929	5·22	8·25	9·53	10·25	17·2	..
October 4, 1929	5·22	8·25	9·53	9·53	17·2	..
October 9, 1929	5·03	8·25	8·97	9·53	17·32	12·22
October 14, 1929	5·03	8·97	9·53	10·25	18·4	12·24
October 18, 1929	5·34	8·25	9·53	10·25	17·32	12·22
October 23, 1929	..	8·25	9·53	10·82	18·4	11·61
October 28, 1929	..	8·25	9·53	10·82	18·4	11·61
November 7, 1929	5·01	7·6		11·6	17·48	..

The osmotic pressure at the root tip increases slowly, remains at its maximum from the 3rd of September up to the 10th of September, and then there is a small fall after which it remains nearly constant. The same is the case at the base of the roots. In the case of the leaf sheath, the maximum osmotic activity of the cells is attained about a week later, and in the case of the lamina on 20th September.

The suction pressure of the root tip rises in the beginning up to the middle of September and then after a slight fall, it remains constant. This is more or less true of the other parts of the plant where it is measured.

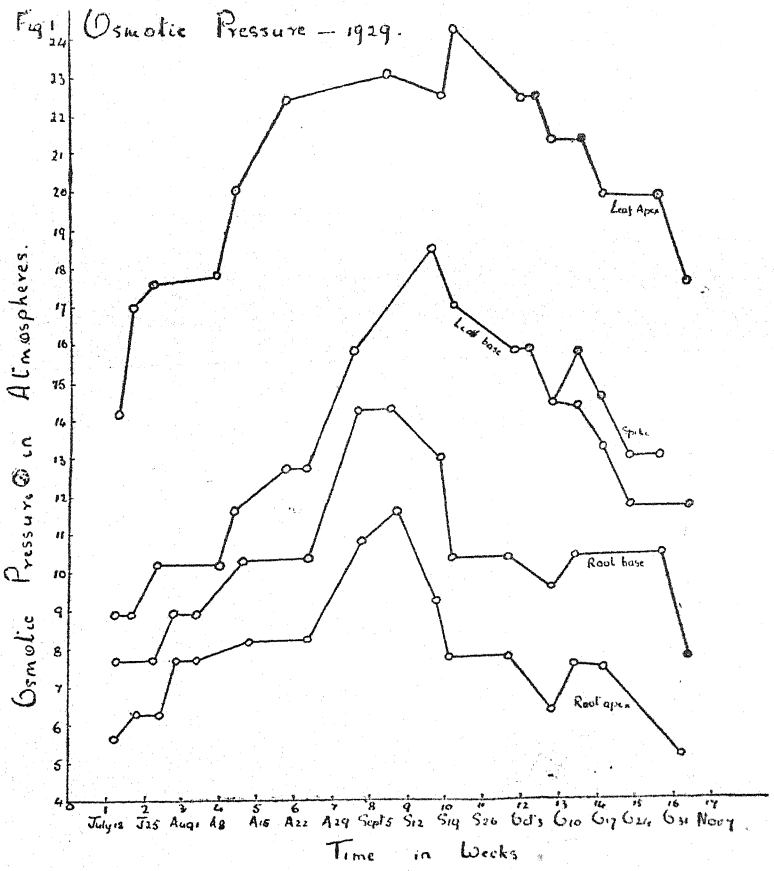

Fig. 1.

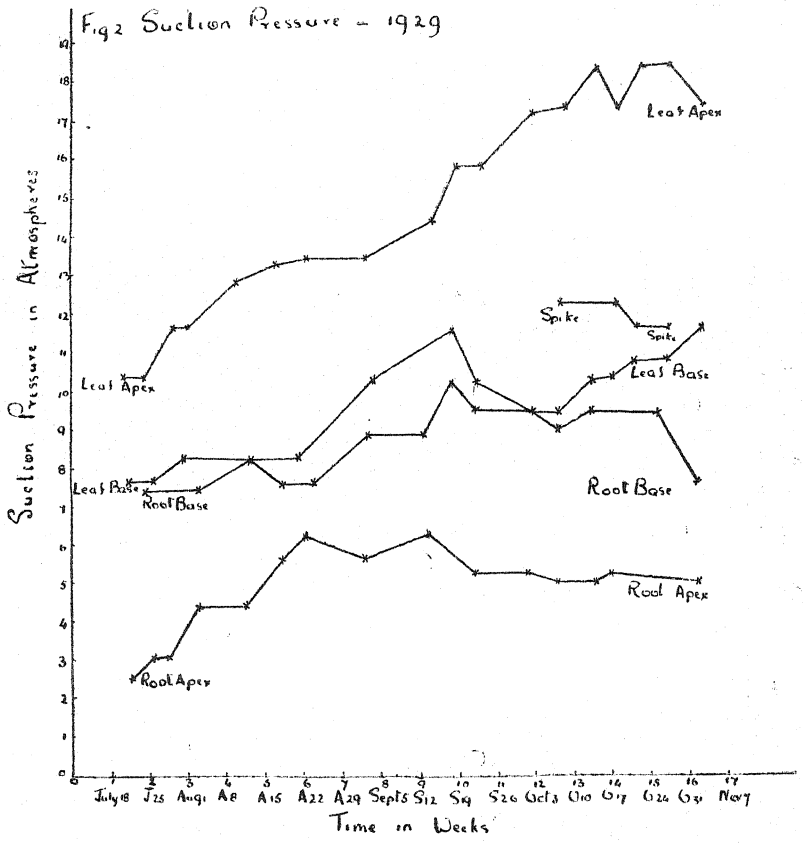

Fig. 2.

In Figures 1 and 2, the osmotic and suction pressures are plotted against the time. The curves of the osmotic pressure of all the plant organs show a continuous rise in the beginning, and then they fall rapidly, while those of the suction pressures show a more or less continuous rise. The wall pressures of the cells in the same regions of the rice plant are obtained by substituting the values of osmotic and suction pressures in the formula.

Suction pressure is equal to osmotic pressure *minus* the wall pressure ; and the values obtained are plotted against time.

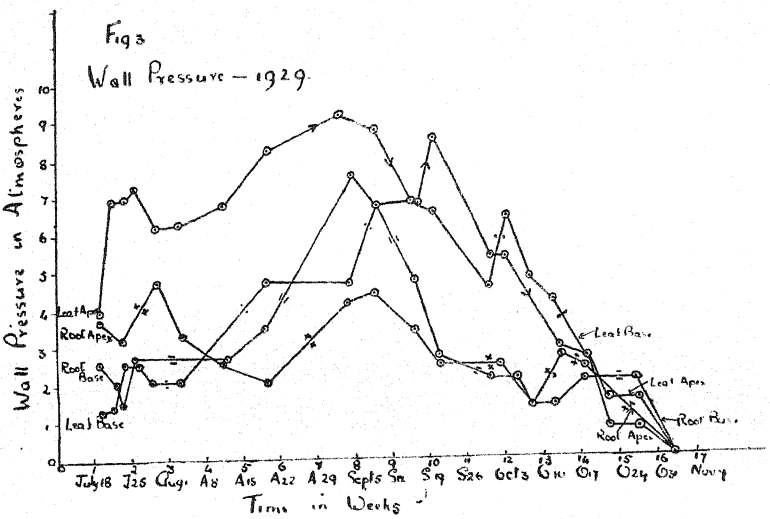

Fig. 3.

In the roots and leaves the maximum wall pressure exists in the cell towards the end of August and in the beginning of September, and they show rapid fall in October (Figure 3). In Figures 4, 5 and 6 the osmotic, suction and wall pressures of the root apex, leaf sheath and leaf apex are shown together, and in all the three cases it is clearly seen that the osmotic pressure becomes equal to the suction pressure by a fall in the wall pressure. There is no corresponding fall in the suction pressure as the wall pressure diminishes.

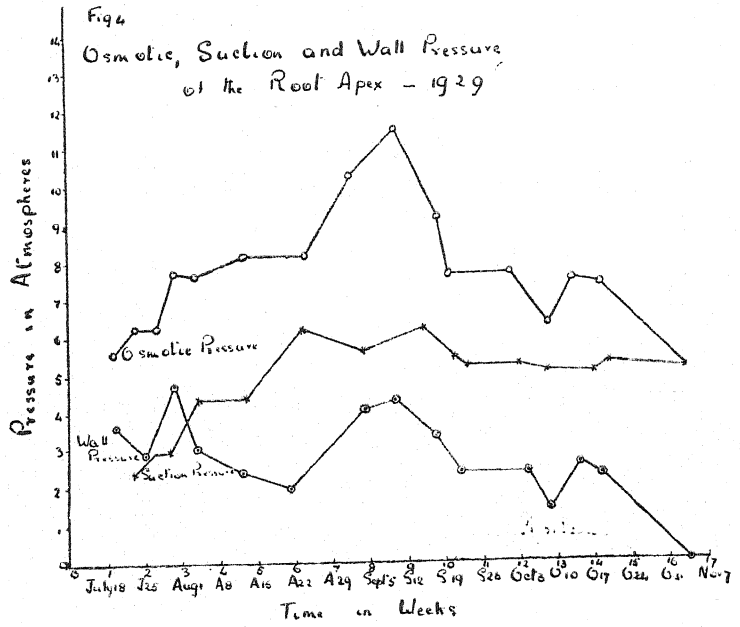
Fig 4
Osmotic, Suction and Wall Pressure
at the Root Apex - 1929
Pressure in Atmospheres
Osmotic Pressure
Wall Pressure
Suction Pressure
July 18 25 Aug 1 8 15 22 29 Sept 5 12 19 26 Oct 3 10 17 24 31 Nov 7
Time in Weeks

Fig. 4.

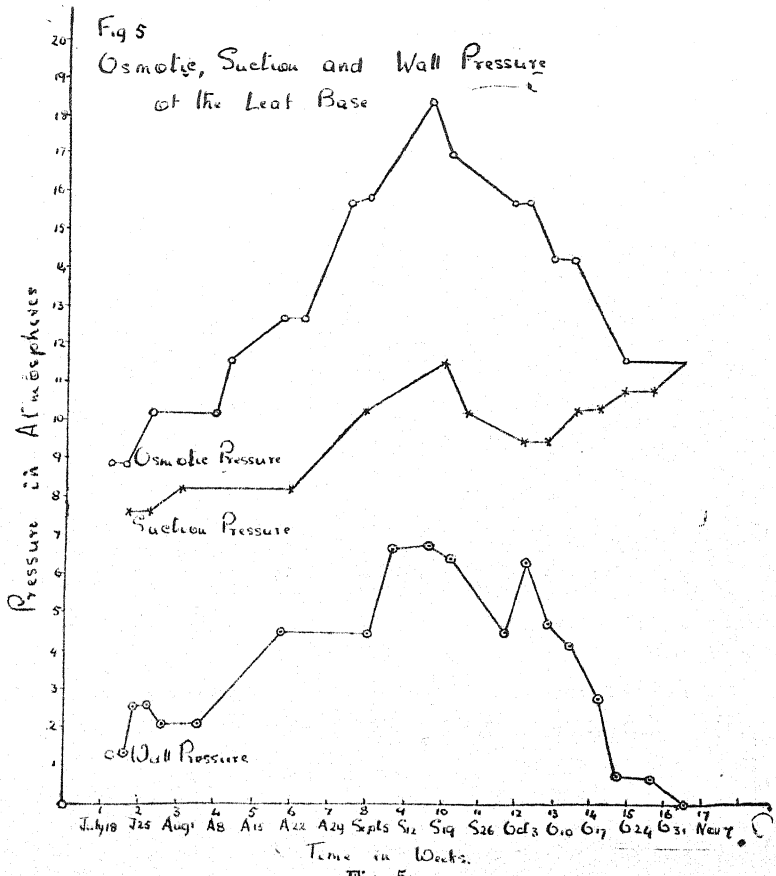
Fig 5
Osmotic, Suction and Wall Pressure
at the Leaf Base
Pressure in Atmospheres
Osmotic Pressure
Suction Pressure
Wall Pressure
July 18 25 Aug 1 8 15 22 29 Sept 5 12 19 26 Oct 3 10 17 24 31 Nov 7
Time in Weeks.

Fig. 5.

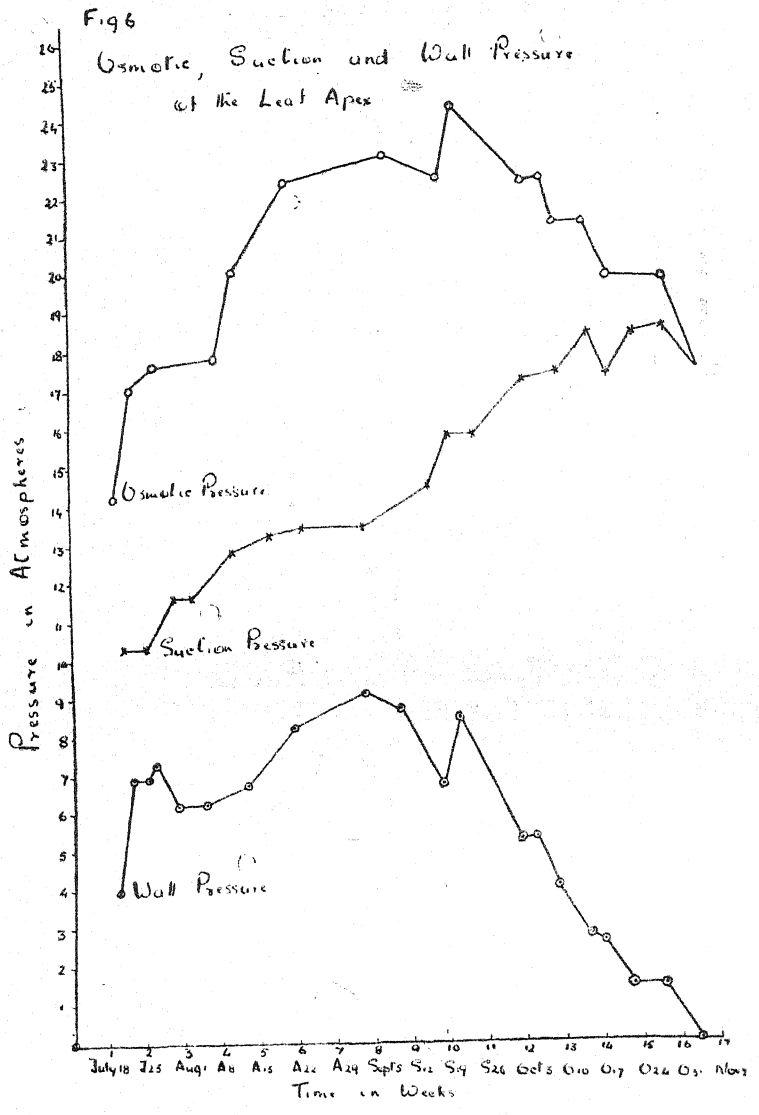

Fig. 6.

Discussion.

The osmotic pressure in the rice plant attains its highest value in the first two weeks of August. It begins to rise after transplantation but shows a depression in the second week of August, after which it reaches its maximum and then begins to fall. Manuring with ammonium sulphate has the effect of increasing the osmotic

pressure in the plants. This is a point of importance as it clearly indicates that the osmotic concentration of the cell sap increases after manuring. A similar rise in the suction pressure was observed. The possibility is that ammonium sulphate is permeable to the roots of the rice plant, which may be the primary cause of its absorption, while nitrates of other metals may not be absorbed which may account for their low values as fertilizers for the rice plant. It is undertaken to test these assumptions by direct measurements. Much light may be thrown on the permeability of ions in the roots, if the degree of permeability of a salt could be measured by the increase in the osmotic and suction pressures of these organs.

Various methods have been employed by different workers to determine the permeability of the vegetable cells to the solutes. Stiles [1924] has described fourteen different methods devised by different workers for the study of absorption of dissolved substances. But no mention is made by them of determining the absorption of salts by measuring the rise in the osmotic pressure or suction pressure of the vegetable cells. If different substances in molecular strengths when added to a soil increase the osmotic pressure in the cells to different degrees, it could be indirectly assumed that the salts are absorbed in different proportions.

It is proposed to follow this line of research next season when the rice plants will be manured at certain stages with different substances and the effect on the suction and osmotic pressures will be studied. This method should prove of value to agriculturists as it would enable them to determine the nature of substances absorbed by the plants and save the lengthy process of making chemical analyses of the plants at different stages of growth.

It is also a very significant fact, that the osmotic pressures and suction pressures tend to become equal towards the termination of the life period of the rice plant. The osmotic pressure becomes equal to the suction pressure when a living cell is artificially plasmolysed by immersion in a strong solution of higher osmotic pressure, *i.e.*, when the turgor pressure and the wall pressure fall to zero. This is the state of the cells in the rice plants in nature at the end of the vegetative and reproductive periods, as the results very clearly indicate (Tables VIII and IX). It means that the cell walls have lost their elasticity and consequently, the cells have lost their turgor pressure which is an important feature of the living cells. The suggestion that the cell walls have lost their elasticity would present an apparent difficulty in the measurement of the suction pressure, as the suction pressure of a tissue is measured by the determination of the strength of the standard solution in which a strip of tissue suffers no change of either elongation or contraction, and if the cell walls have lost their elasticity, the measurement of the suction pressure should be an impossible task. But on studying the actual figures giving the percentage elongations and contrac-

tions of the different strengths during the whole season, it is seen that the percentage elongation or contraction of the tissue decreases from July to October showing that lesser and lesser changes in the strips of tissue take place as the season advances, so much so that towards the end every little measurable change in dimension is noticed, and the difference in the percentage elongations or contractions of the strips of tissues in two solutions, different in concentration by 0·15 M, become less and less as the following figures show :—

TABLE X.

Percentage elongations or contractions of the strips of tissues in the different organs of the rice plant from July to October, 1928.

Variation per cent. in original lengths of strips of tissues after being carried from paraffin oil to cane sugar solutions of 0·15 difference.

Difference in concents.	July	August	September 1st week	September last week	October 1st week	October last week
Root apex.						
	—1·43	—1·8	—1·8	0·4	—1·4	..
0·15	1·93	3·1	3·35	2.31	0·81	..
Total Variations . . .	3·36	4·9	5·15	2·71	2·21	..
Root vas.						
	..	3·75	3·9	1·7	1·01	0·24
0·15	..	2·9	6·0	2·9	0·362	0·58
Total Variations . . .	..	6·65	9·9	4·6	1·372	0·82
Root cort.						
	3·4	3	4·9	2·04	0·65	0·73
0·15	1·3	2·3	1·39	2·15	0·51	0·19
Total Variations . . .	4·7	5·3	6·29	4·19	1·16	0·92

Difference in concents.	July	August	September 1st week	September last week	October 1st week	October last week
Leaf sheath.						
	1·5	1·56	1·5	2·6	2·3	0·44
0·15	1·7	1·94	2·98	1·18	0·65	0·22
Total Variations . . .	3·2	3·5	4·48	3·78	2·95	0·66
Leaf apex.						
	0·67	2·12	1·44	0·57	0·82	0·207
0·15	2·32	1·06	4·2	2·3	0·38	0·422
Total Variations . . .	2·99	3·18	5·64	2·87	1·2	0·629

Summary.

The osmotic pressure of the roots and leaves is determined by the plasmolytic method of De Vries, different molecular concentrations of sugar solutions being used as plasmolysing fluids. The pressures in atmospheres corresponding to each strength of molecular solution are taken from the tables given by Molz [1926], and Ursprung and Blum [1916, 1, 2]. The osmotic pressures of the tissues at the root apex, root base, leaf sheath, and leaf apex are determined. The pressures given are the average osmotic pressures of the cells of each part of the plant.

The osmotic pressures in all cases show a periodicity. In general terms, the osmotic pressure begins to rise as the season advances, reaches a maximum and then falls. Slight fluctuations of the osmotic value are noticed during the early stages after transplantation. Manuring with ammonium sulphate seems to increase the osmotic pressure in the roots and the leaves. The osmotic pressure of the root increases from apex towards the base and in the leaves from the base towards the apex, and the same relations between the osmotic pressures of the root apex, root base, leaf sheath and leaf apex are maintained during the whole active period. The osmotic pressure of the roots fluctuates between 14 and 5·02 atms. and of the leaf between 10·25 and 24·12 atms.

2. The suction pressure of the same organs is determined during the whole season. The suction pressure values also show a similar periodicity as the osmotic

pressure. Manuring has a similar effect on suction pressure. The suction pressure at the end of the season goes up, which is the point of importance, and fresh simultaneous measurements of the osmotic pressure and suction pressure show that at the end of the season, the suction pressure is very nearly equal to the osmotic pressure. The suction pressure of the spike shows a continuous rise after which it remains constant. The suction pressure of the roots fluctuates between 3 and 5·5 atms. at the apex and from 4 to 12 atms. at the base. The suction pressure of the leaves fluctuates between 7 and 14 atms. at the base and from 10·5 to 19·3 atms. at the apex.

3. It is suggested that the changes in osmotic pressure produced by the absorption of a salt can be made use of for determining whether a salt is absorbed by a plant or not.

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ON THE NATURE OF THE REACTIONS RESPONSIBLE FOR SOIL ACIDITY.

PART I. ON THE TITRATION CURVE OF ACID CLAY.

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With four text-figures.

THEORETICAL CONSIDERATIONS.

The nature of reactions responsible for soil acidity has been the subject of controversies. Two rival points of view are met with: (1) The reactions involve complex insoluble alumino-silicic acids and are of the usual type. This view is known as the true acid theory [Chemical Society, London, 1924, 1925, 1], (2) "Physical" adsorption processes as distinct from ordinary chemical reactions are responsible for the acidity. Bradfield [1923,1924] has dealt with the advantages of the first. His work has a direct theoretical interest. The colloidal fraction has been separated from soil as a "physically homogeneous mass" by centrifugal force. "The colloidal fraction of an acid soil" is considered to be "itself an acid which ionises to produce a definite Soerensen value and show a definite titratable acidity or normality on titration with strong bases. The fact that the acid is colloidal explains why it is not found in colloid-free aqueous extracts. The anions of the soil acid" are "the charged colloidal particles". The properties of saturated, unsaturated and infinitely dilute solutions of such colloidal acids, their strengths and dissociation constants form the subject of investigation.

Reactions in the interface are referred to by supporters of both theories. The adsorption theories are termed physical, probably because the adsorption is attributed to capillary forces as embodied in the classical work of Gibbs, Freundlich and others. The adsorption theories of soil acidity, as developed by

Cameron [1910], Parker [1913] and Harris [1917], postulate the adsorption of bases from neutral salts of a strong acid and a strong base and consequent liberation of acids. It does not go into the mechanism of the process, but apparently considers it to result from capillary forces. The essential similarity with chemical systems constitutes the main basis of the true acid theory (Cp. the views of Billitzer, Duclaux, Pauli and Soerensen on colloidal systems). It is sometimes recognised however (Chemical Society, London, 1925, 2) that reactions involving the interface would have somewhat different condition of equilibrium. The concept of a colloidal acid as usually formulated appears to suffer from some limitations common to theories which treat colloids as ordinary electrolytes. [Mukherjee, 1922, 1925, 1926, 1929]. The different fractions of the colloidal acid separated by graded centrifugalisation, *may* have particles of different size. Each fraction *may or may not* be considered as a distinct solid phase and the 'molecular' concentration of the saturated solution *may* vary with the size of the particles. The molecular weight would admit of a continuous variation with the size of the particles. Similarly the basicity of these polybasic acids will probably depend on the size of the particles. Besides in most colloidal solutions the particles are not of the same size.

A constant total acidity on titration with excess of different strong bases shows, either, that a given mass of the colloid contains a definite mass of hydrogen ions capable of neutralisation, or, that a given mass adsorbs on its surface a definite amount of hydroxyl ions. But the stoichiometric character of ordinary acids consists in the stoichiometric nature of the ratio of the number of replaceable hydrogen atoms to that of each other type of atom in the acid molecule. The molecular weight and the basicity of an acid molecule are fixed. These stoichiometric relationships are lacking in colloidal systems [Mukherjee, 1925]. Such colloidal particles would show a progressive reaction with base with time as successive layers are exposed. If the particles be very small they may react *en masse* very rapidly and simulate acid "molecules". The manner of variation of the pH of solutions of the colloidal acid with different amounts per unit volume as observed by Bradfield, would also be expected in case acids were present in the interface in adsorption equilibrium with the intermicellary liquid (which will determine the limiting minimum value of the pH). Further, systems of charged particles with a double layer may show the observed variation without it being necessary to regard them as solutions of weak acids. These aspects will be dealt with in this series of papers as being of importance in interpreting experimental results.

In this paper simpler reactions involving the interface between a solid (acidic or basic) and a liquid where the former is present in excess of the quantity

required for crystalloidal saturation have been studied. The following systems have been dealt with :—

(A) Titration curves of saturated solutions of cinnamic, *iso*-phthalic, and *p*-toluic acids with or without excess of the solid phase and varying times for interaction *after each addition* of alkali.

(B) Aluminium hydroxide sol.

Experimental.

Electrometric titrations (e.m.f.) were performed with hydrogen cells against normal calomel electrodes. A Leeds Northrup K type potentiometer was used. Three sets of titrations (with caustic soda) were performed (35°C.), (1) with saturated solution, (2) with a known weight of the acid in excess of that required for saturation (the hydrogen bubbles keep the solid in suspension); (3) as in (2) but in a set of bottles with varying amounts of alkali the mixture was vigorously shaken and left for 48 hours.

The hydrogen electrodes used were of the Hildebrand type. In the form used, a fairly wide glass tube was taken as the main vessel, the top of which was closed with a cork having two bores. Through one a tube containing a platinum foil was introduced and through the other a micro-burette reading up to ·01 c.c. was inserted. Hydrogen entered at the bottom of the tube and escaped through a small trap. The main tube was also provided with a side-tube fitted with a stopcock.

The e.m.f. was steady after hydrogen had been passed for about 30 minutes; after the e.m.f. had been noted alkali was again added. A saturated KCl bridge was inserted between the narrow side-tube of the hydrogen vessel and the calomel electrode. There was thus two junction potentials on the two sides of the trap. The observations indicate more reliably the *relative* changes in the pH. The bulk of the alkali (NaOH) was taken in a bottle coated inside with high melting pure paraffin, and the requisite quantity of baryta was added to the caustic soda solution to free it from carbonate and kept free from contact with the atmospheric carbon dioxide. The solutions were made decinormal with regard to potassium chloride by dissolving the solid so as to make them sufficiently conducting. Where the solubility of the substance was moderate it was sufficient to add 0·14 grm. of KCl to 20 c.c. of the saturated solution. This volume was used for titration. The total volume of the alkali or acid added during titration was between 2—2·6 c.c.

The aluminium hydroxide sol was prepared by adding slightly less than the equivalent amount of ammonium hydroxide solution (normal) slowly and with vigorous stirring to a solution of aluminium chloride (normal). The resulting sol was purified by 'hot dialysis' (70°C.) for 15 days. A trace of chlorine was still present. The chlorine-ion concentration was determined by means of silver chloride electrode [Noyes and Ellis, 1917]. The total chlorine was determined by dissolving 50 c.c. of the sol in a boiling solution of moderately concentrated nitric acid and measuring the chlorine-ion concentration by the silver chloride electrodes. The change of pH with dilution of the sol was determined by the hydrogen electrode. The solution contained 0·14 grm. of KCl per 20 c.c. Electrometric titration of aluminium hydroxide sol and its dilutions containing excess of alkali were carried out with hydrochloric acid. The pH of dilutions of the sol was also determined after neutralising the acid corresponding to the free chlorine by adding the requisite amount of alkali to the sol. The strength of the NaCl formed was calculated and all dilutions of this neutralised sol contained the same concentration of this salt. This 'neutral' sol and its dilutions were also electrometrically titrated. Similar experiments were carried out after neutralising the acid corresponding to the total chlorine. Lastly conductometric titrations of the original sol and some dilutions were also performed.

Results and Discussions.

A. The dissociation constants have been calculated from the approximate equation.

$$pH = pK + \log \frac{[\text{salt}]}{[\text{acid}]}, \qquad (1)$$

where $pH = \log \frac{1}{[H]}$ and $pK = \log \frac{1}{K}$, K being the dissociation constant of the acid. The saturated solutions present no difficulty if the concentration of the salt is taken as equivalent to the amount of alkali added and the residual acid calculated in the usual way. In the other cases, K has been calculated by using (i) the total quantity of acid including the solid, (ii) the constant strength of the saturated solution of the (strictly the undissociated) acid, and (iii) the approximate neutralisation point indicated by the titration curve. These values of K ($\times 10^5$) are given respectively in columns 5, 6 and 7 of Tables I to VI.

Column 1 gives c. c. alkali; 2, the concentration of the salt; 3, that of the free acid; 4, pH and 5, K ($\times 10^5$). The concentrations of salt and pure acid are given as moles per litre.

TABLE I.

Cinnamic acid (1).

Saturated, without solid phase : 0·5624 grm. per litre ; 0·1086 *N* NaOH used.

1	2	3	4	5
0	..	·0038	3·439	..
0·16	·000861	·002939	4·055	2·63
0·24	·001287	·002413	4·275	2·75
0·40	·002129	·001671	4·607	3·16
0·48	·002545	·001255	4·834	3·02
0·64	·003367	·000433	5·413	3·02
0·80	Excess alkali.		9·585	..
0·88			9·836	..

TABLE II.

Cinnamic acid (2).

With solid phase : total acid ·62 grms. in 20 c.c. ; 0·1086 *N* NaOH used ; e.m.f. measured within 30 min. after the addition of alkali. In columns 5, 6 and 7, K ($\times 10^5$) has been calculated as explained before.

1	2	3	4	5	6	7
0	..	·006757	3·442	..	..	..
0·08	·000432	·006325	3·518	2·09	3·47	3·02
0·12	·000647	·006110	3·737	1·95	3·09	2·88
0·16	·000861	·005896	3·852	2·04	3·16	3·09
0·26	·001393	·005364	4·098	2·09	2·95	3·31
0·42	·002234	·004523	4·428	1·82	2·19	3·31
0·58	·003061	·003696	4·740	1·51	1·48	3·31
0·74	·003874	·002883	5·041	1·23	0·933	3·98
0·88	·004577	·002180	5·477	0·692	0·398	8·91
1·04	Excess alkali.		10·103	..	..	..
1·18			10·298	..	..	..

Table III.

Cinnamic acid (3).

Excess solid: pH after 48 hours: interaction with alkali, 0·1086 *N* NaOH: K × 10^5 in columns 5 and 6 calculated as in Table II.

1	2	3	4	5	6
0	..	·006757	3·444	..	..
0·1	·000540	·006217	3·671	1·86	3·02
0·6	·003211	·003546	4·254	5·01	4·68
0·7	·003672	·003085	4·383	4·90	3·98
1·0	·005171	·001586	4·791	5·25	2·2
1·2	·006147	·000610	5·288	5·13	0·83
1·3	Excess alkali.		7·891	..	..
1·4			..	..	..

Table IV.

p-toluic acid.

Saturated solution without solid phase: 5·37 grms. per litre: 0·1111 *N* NaOH used.

1	2	3	4	5
..	..	·003777	3·377	..
0·12	·000662	·003115	3·691	4·37
0·20	·001100	·002677	3·914	5·01
0·32	·001749	·002028	4·249	4·90
0·47	·002555	·001222	4·631	4·90
0·58	·003131	·000646	5·259	2·69
0·68	Excess alkali.		8·778	..
0·79			10·319	..
0·94			10·649	..
1·05			10·769	..

TABLE V.

p-toluic acid.

Excess solid present: total acid ·02 grm. in 20 c.c.; 0·1111 *N* NaOH used; measured within 30 minutes after addition of alkali; K × 10^5 in columns 5, 6 and 7 calculated as in Table II.

1	2	3	4	5	6	7
..	..	·007353	3·413	..	..	..
0·08	·000442	·006911	3·641	1·44	2·62	2·57
0·20	·001100	·006253	3·836	2·57	4·27	5·01
0·32	·001749	·005604	4·137	2·29	3·40	4·90
0·44	·002391	·004962	4·388	1·95	2·57	5·01
0·57	003078	·004275	4·585	1·86	2·14	5·01
0·74	·003964	003387	5·016	1·12	1·02	..
0·86	} Excess alkali.		9·224	..	..	..
0·98			9·689	..	..	..
1·10			9·901	..	..	..

TABLE VI.

p-toluic acid.

Excess solid present: pH after 48 hours contact with alkali: total acid 0·02 grm. in 20 c.c. 0·1111 *N* NaOH used: K × 10^5 in columns 5 and 6 calculated as in Table II.

1	2	3	4	5	6
..	..	·007353	3·383	5·25	6·46
0·5	·002709	·004644	4·045	5·25	5·01
0·7	·003757	·003896	4·299	5·25	4·37
0·8	·004273	·003080	4·418	5·25	2·88
1·0	·005290	·002063	4·692	..	..
1·2			4·985	..	..
1·3			5·442	..	..
1·4	Excess alkali.		9·281	..	..
1·5			9·611	..	..
1·7			10·008	..	..

TABLE VII.

Isophthalic acid saturated solution.

0·1111 *N* NaOH used.

NaOH (c.c.)	0	·08	·24	·40	·48	·56	·64	·72	·80
pH	3·30	3·41	3·83	4·54	5·61	7·69	8·87	9·18	9·41

Excess of solid present: interval of 30 minutes; ·01 grm. of acid in 20 c.c.

NaOH (c.c.)	0	·05	·10	·15	·25	·35	·45	·55	·65	·75	·85
pH	5·31	3·43	3·57	3·74	4·00	4·30	4·61	4·97	5·58	9·41	10·08

As above after 48 hours.

NaOH (c.c.)	0	·10	·50	·80	1·10	1·20	1·30
pH	3·30	3·48	3·94	4·42	5·41	8·4	9·45

The results are given in curves 1, 2, 3 respectively in Figure 1.

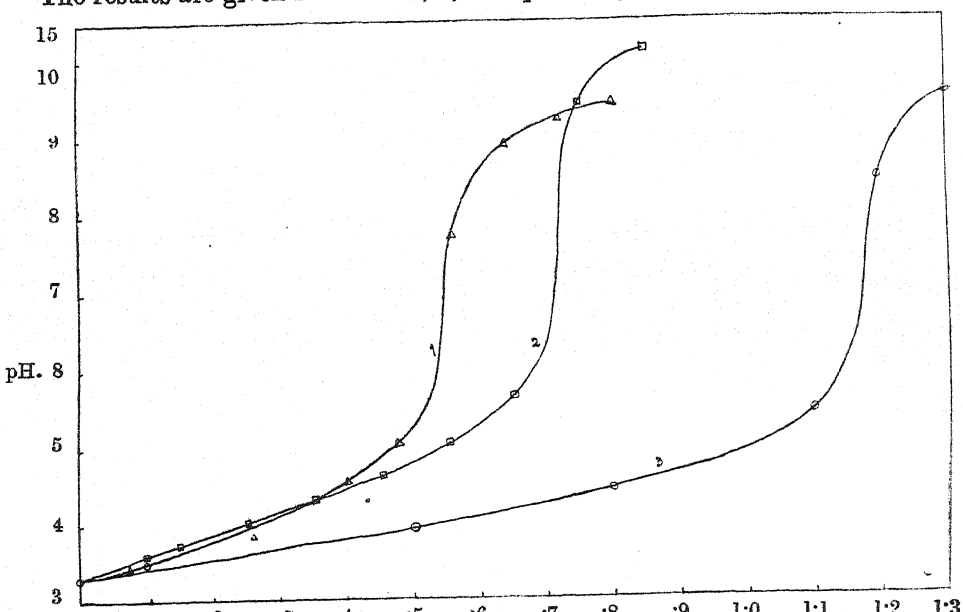

Fig. 1.

The preceding observations present features characteristic of a sparingly soluble acid when the solid phase is also present. In interpreting the titration curves the rate of reaction at the interface has to be considered and a difficulty is met with in finding out the concentration of the acid in equation (1). In case of a colloidal solution of an insoluble complex (*e.g.*, alumino-silicic) acid the stoichiometric concentration of the acid and its basicity are unknown. There is definite evidence that these colloidal particles (*e.g.*, ferric hydroxide or copper ferrocyanide) carry a fairly large number of units of electronic charges. But Bradfield obtained evidence of two dissociation constants only*. In the present work also there is evidence of one dissociation constant only inspite of the particles having a large dimension than what is usual with colloidal particles.

In Tables II to VI, column 7 shows the least variation in the dissociation constant. The total acidity of the solution of an unknown acid in suspension (or colloidal solution) would be determined from the neutralisation point, preferably of a conductometric titration curve. But its theoretical significance is not the same as for molecular crystalloidal solution of an acid. For (*a*) a comparison of the preceding tables will show that the time of interaction determines the effective total acidity; (*b*) the stoichiometric concentration of the total acid of the unneu-

* Puri [1930] has recently shown that the acidoid in a fully unsaturated soil behaves like a tri-basic acid.

tralised acid, *i.e.*, the number of molecules (particles of colloidal acid) per unit volume (litre) cannot be estimated unless the basicity is known, (*c*) the stage of dissociation involved should have to be considered, (*d*) also if we take the maximum amount of neutralisable hydrogen ions for the calculation (column 5), the dissociation constants are less satisfactory than in column 7. If the colloidal particles of the clay are to be regarded as molecules of a polybasic weak acid (either in successive stages of dissociation or undissociated), then the neutralisable amount should be used for the calculation as in column 5. Theoretically column 6 should give the most satisfactory constants. The deviation is to be ascribed in part to the use of the approximate equation but cannot be wholly accounted by it. When the alkali had sufficient time for the interaction (Tables III and VI), the method of calculation used in column 6 gives values of the dissociation constant which remain steady up to a much higher alkali concentration. The wide variations in the constants should be ascribed in part also to the insufficient time (30 min.) for attainment of the equilibrium. The smaller dissociation constant indicates that the concentration of the acid used in calculating the constant is greater than what actually exists in the solution. In addition to the non-attainment of the equilibrium, the concentration of the total free acid will be less than that in a saturated solution in view of the high concentration of the salt. The constancy in column 7 is, therefore, misleading so far as indications of actual dissociation constants of cinnamic acid are concerned. Similarly the remarkably smooth curves in Figure 1 show on first sight as if there were three monobasic acids with dissociation constants increasing from curve 1 to 3. The dibasic character of the acid is not brought out.

Colloidal solutions, however, present *additional* features which make the interpretation of titration data more difficult.

B. Aluminium hydroxide sol.—Colloidal solutions may or may not be one-phase system [Indian Science Congress, 1929], *but it cannot be denied that interfaces take part in reactions in them*. The interaction between ions in the intermicellary solution and the solid side of the interface play an important part in inorganic colloids. It is necessary to distinguish between the properties of the interface of the *pure* colloid and the liquid apart from those of the interface resulting from reaction with solutes in the solution. The aluminium hydroxide sol had a total concentration of chlorine equal to 0·006 *N*. Sol B was obtained by neutralising the free chlorine by addition of the requisite amount of alkali. The total chlorine was neutralised in a similar manner (Sol C), and the hydrogen-ion concentration of the two sols determined for different dilutions. $C_{Cl'}$ gives the free chlorine-ion concentration, C_{Cl} the total chlorine and C_H the hydrogen-ion concentration. The three sols had different aluminium-contents.

TABLE VIII.

Dilution	A			B	C
	$Ccl \times 10^4$	$Ccl' \times 10^4$	$C_H \times 10{\cdot}5$	$C_H \times 10^5$	$C_H \times 10^7$
0	60	29·30	10·2	7·9	5·9
2	30	14·70	8·5	3·8	3·6
4	15	8·04	5·5	1·9	2·4
8	7·5	5·31	3·8	1·0	1·7

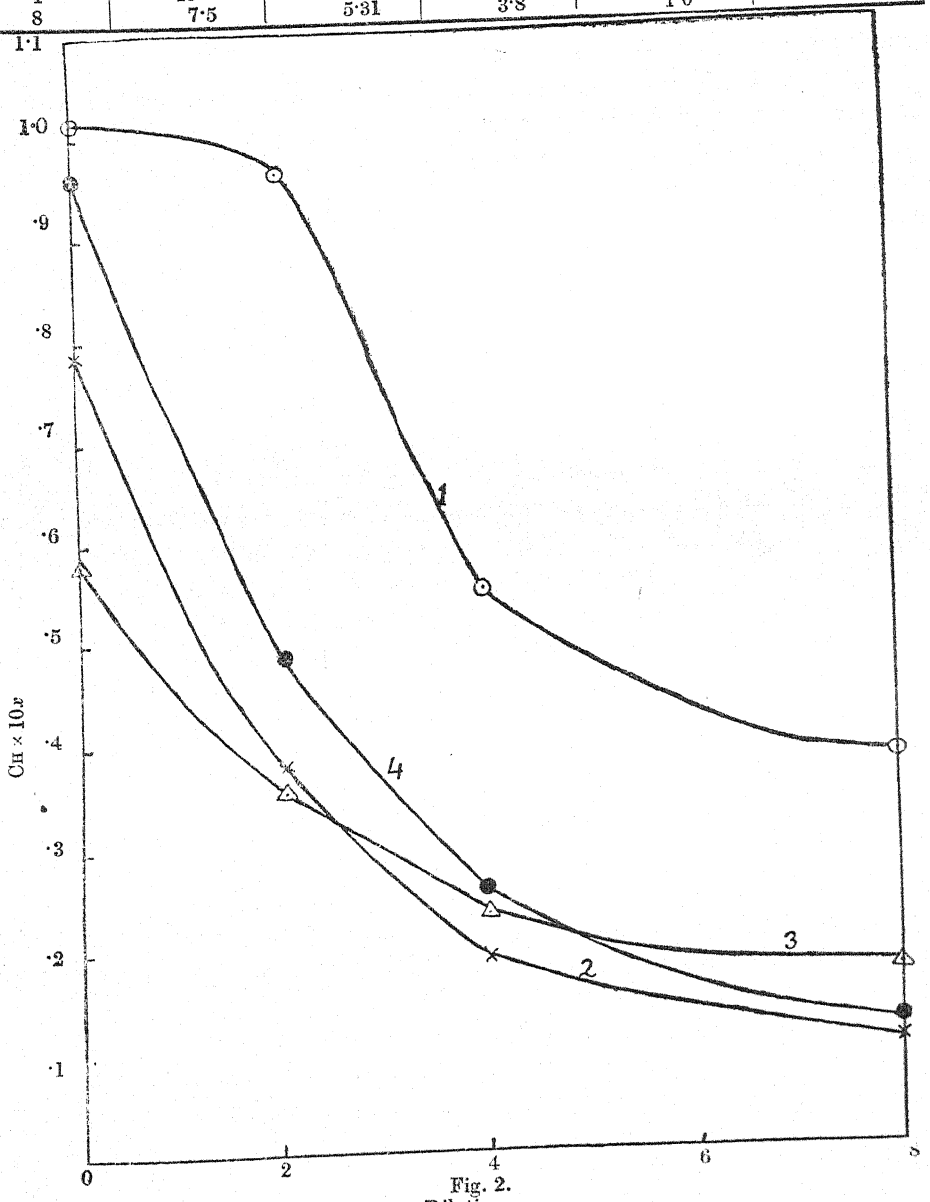

Fig. 2.

Dilution.

For curve 1, $x=4$; for curve 2, $x=5$; for curve 3, $x=6$; for curve 4, $x=4$.

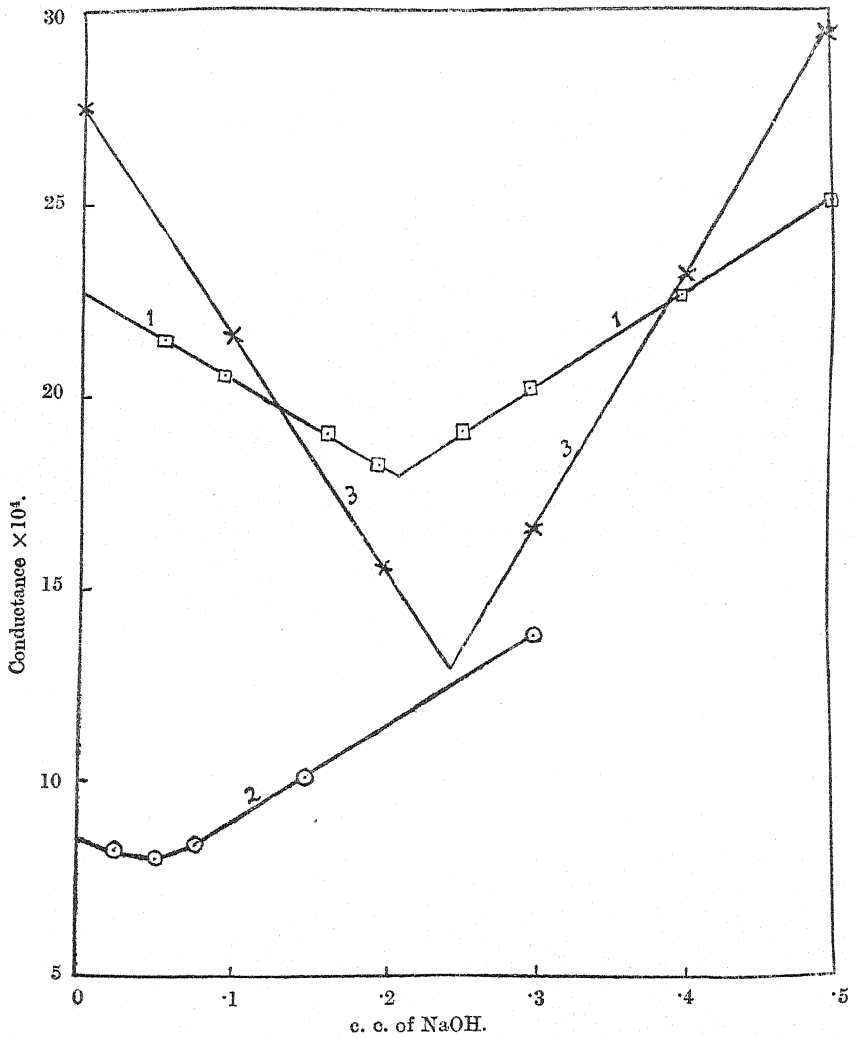

Fig. 3.

Carbon dioxide from the atmosphere was present in the solution. This should be taken into account. Curves 1, 2, 3, 4 (Fig. 2) give respectively the hydrogen-ion concentration of Sols A, B, C and pure hydrochloric acid as measured with the same arrangement. The conductometric titrations of sol A (dilutions 4 and 8) and of pure hydrochloric acid are given in curves 1, 2, 3, respectively, of Fig. 3. From Fig. 2 the total acidity for the two dilutions are found to be respectively 2×10^{-4} and $1{\cdot}2\times10^{-4}$. They are thus intermediate between the free hydrogen and chlorine-ion concentrations (Table VIII). These values as also the curves in Fig. 2

show that sols A and B behave on the whole as fairly strong acids. The initial portion of curve 1, Fig. 2 show that aluminium ions present, either on the solid side of the interface, or, in a state of solution, hydrolyse on dilution and produce a buffer action resisting the diminution of the hydrogen-ion concentration on dilution. The differences in the slopes of the curves in Fig. 3 also show that aluminium ions are taking part. The great similarity in the form of the curves 2 and 4 in Fig. 2 probably indicates that the aluminium ions are small in number in sol B and that dilution merely changes the hydrogen-ion concentration of the intermicellary solution. The departure from a straight line in both cases is to be ascribed to the conductivity of the water used and to carbon dioxide (possibly also traces of ammonia). Curve 3 shows that such impurities are present. These observations bring out one fact unmistakably, namely, that the electro-chemical properties of the sol more resemble those of a moderately strong acid than those of a weak base in colloidal solution and that the interaction between aluminium hydroxide and hydrogen ion, as affected by the dilution or the concentration of the latter or the extent of the interface, is the most significant factor. Bradfield's method of preparation of the colloidal clay acid does not seem to render it free from the small traces of electrolytes involved in the present experiments or *free* aluminium hydroxides or free silicic acid. The nature and amount of these electrolytes are of great influence on the properties of colloidal solution of insoluble acids or bases. In this particular instance the acidity as measured by conductometric titration has very little to do with the colloidal substance. The electrolyte (hydrochloric acid) present in the sol plays the dominant part.

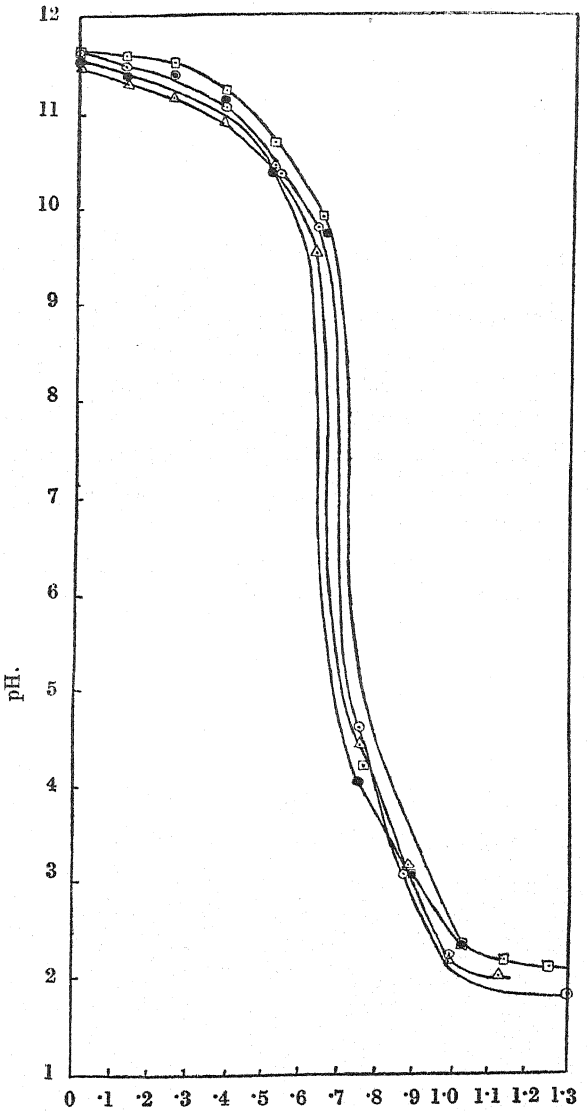

Fig. 4.

Titration curves of Aluminium Hydroxide Sol. Symbol ⊙ refers to Sol A (dilution zero), while ▲ refers to the same after two days' interaction with alkali. ⊡ refers to Sol A doubly diluted, while ● refers to the same after two days' interaction with alkali.

Titration experiments with excess of base were performed. These have the interest that the acid is eliminated and the acidic character of the ampholyte is

likely to be indicated. The data are given in Fig. 4. 7 c.c. of 0·1111*N* sodium hydroxide were added to 20 c.c. of the sols A, B, C and the pH corresponding to different volumes of a normal solution of hydrochloric acid was measured. These curves also show the expected effects of time and the interaction of the interface with the electrolytes in solution. The initial portion of the curve also indicates (compare titration curves of hydrochloric acid with those of weak acids and pH of mixtures of sodium citrate or borate with hydrochloric acid Clarke, 1928), that we are dealing in the main with neutralization of a strong base by an acid. As is to be expected the added alkali plays the dominant part. The acidic properties of aluminium hydroxides are so weak that the extent of interaction between it and the alkali produces very little difference in the corresponding curves.

It is not claimed that the systems dealt with in this paper present features identical in every respect with the colloidal clay acid or soil. These simpler systems have to be studied in detail before the validity or otherwise of the rival points of view is established and they serve as a guide to further work which will be dealt with in subsequent papers.

The continuity of this work has been furthered by a grant from the Imperial Council of Agricultural Research and we thank the Council for their help.

Summary.

1. Titration curves of saturated solutions of cinnamic, *iso*-phthalic and *p*-toluic acids both in presence and absence of excess of the solid phase and for different times of interaction with the alkali have been given. It has been shown that although excess of solid is present, evidence of only one dissociation constant is obtained and that its value depends, as is to be expected, on the condition of interaction.

2. That part played by traces of electrolytes present in colloidal aluminium hydroxide in determining their behaviour and its relation to the interpretation of titration curves have been pointed out.

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STUDIES ON *PLATYEDRA GOSSYPIELLA*, SAUNDERS, IN THE PUNJAB.

PART II. THE SOURCES OF *PLATYEDRA GOSSYPIELLA* INFESTATION.*

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(WITH ONE TEXT-FIGURE.)

Foreword.

In April 1926, the Indian Central Cotton Committee, Bombay, sanctioned a research scheme, financed by a non-recurring grant of Rs. 6,000 for apparatus and laboratory equipment, and an average recurring grant of Rs. 17,000 per annum for a period of five years. The scheme, the total cost of which amounts to about a *lakh* of rupees, makes provision for a staff of one Assistant Cotton Entomologist, three Field Assistants, one Statistical Assistant, one clerk and a dozen of fieldmen.

The present paper deals with a portion of the investigation carried out under this scheme. This contribution deals with the caterpillars in hibernation and the environmental factors which influence their development and emergence of moths which start infestation on the next crop.

The responsibility for the data collected falls on the three Field Assistants. The Assistant Cotton Entomologist is responsible for compilation and has been helped in this work by the Statistical Assistant.

The work was done under the guidance and supervision of the undersigned.

It is suggested that, if a scheme for treatment of seed is inaugurated, fumigation under vacuum should be given a trial. It seems that this method will be more efficient and economic than heat treatment of the seed.

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I. Introductory.

THE SHORT AND LONG-CYCLES.

It has now been definitely established that, in the Punjab, the life-cycles of *P. gossypiella*, Saund., are of two different types, the one in which the caterpillars immediately pupate at the end of their feeding period—the short-cycle—and the other in which the caterpillars even when full-fed and full-grown do not pupate but pass through a prolonged period of hibernation—the long-cycle. In the first case, generation after generation follows in succession, the duration of each life-cycle varying from 19 to 37 days. Thus there may be four broods of this insect from

August to November. In the second case the long-cycle caterpillars hibernate in November. The maximum duration of hibernation so far recorded from the Punjab has been ten months. Ordinarily, however, this period does not exceed eight months [Bindra, 1928]. It is on record that in Egypt the period of hibernation of the long-cycle Pink-Bollworms may extend to two years [Willcocks, 1916].

The Role of the Long-cyclers in starting Infestation.

It is now fully established that in tracts where winter is severe, the infestation of *P. gossypiella*, Saund., is carried from one cotton crop to the following cotton crop through the moths developing from the long-cycle caterpillars [Gough, 1916; Ballou, 1920; Williams, 1924; Chopra, 1926, 1927; Richards, 1927; Afzal Husain, 1928, 1929]. That being the case in the Punjab, a study of the environmental factors to which the caterpillars are subjected during their period of hibernation is of very great importance. The incidence of attack would be regulated in the first place by the factors which influence the life of caterpillars during hibernation, and the subsequent emergence of moths.

Winter-quarters of P. gossypiella, Saund.

For a hibernating insect—which has not the capacity of active movement—the quarters where it settles for hibernation are of very great importance, as its chance of successfully completing its life-cycle depends on the security afforded to it. A study of the hibernating quarters of *P. gossypiella*, Saund., in relation to environmental factors is, therefore, of very great value. Moreover, such places serve as reservoirs for the spread of this pest and are a source of menace to the next cotton crop, and a knowledge about them would be of great help in devising measures of control.

II. The Cotton Crop.

Before dealing with the observations on the pest, it will not be out of place to give a brief account of the cotton crop. In the Punjab the cottons are mainly grown in the plains. The average annual area under cotton for the last five years (Appendix I) has been about two and a half million acres: two million acres irrigated (canals and wells) and half a million acres unirrigated (*barani*). The varieties of cotton grown are classified as the *desis* (indigenous) and Americans. While the American varieties are mostly grown in the irrigated tracts, the *desis* are grown both on the irrigated and unirrigated lands.

Sowing period.

The sowing time of cotton extends from the beginning of April to the beginning of July, depending on local conditions. In the irrigated tracts, the sowing is usually done in April-May, but sometimes it is delayed till June. In the unirrigated, *i.e.*, *barani* areas, the time of sowing depends entirely on the rains, and fluctuates from April to July.

Seasonal-history.

The floral buds begin to appear in June and continue to appear till November. The main rush of flowering is during September and October. The bolls begin to form early in August, but up to September only a few develop. The bolls appear in largest numbers during October and November.

Picking period.

The time of picking varies in differnt tracts, and during different years. According to Milne [1920], cotton picking in wet years may commence several weeks later than in dry years. During years of normal rainfall the picking season for the *desi* cottons extends from the middle of September to the middle of December, and for the American cottons from the beginning of October to the end of January. As regards the number of pickings, there is no definite rule, usually there are six pickings for the *desi* cottons and four for the Americans.

III. The Seasonal-history of Pink-Bollworm in the Punjab.

Time of attack.

In the Punjab the season's first attack of Pink-Bollworm generally starts in the beginning of August, but on ratoon cottons it may appear a little earlier—last week of July. This has been confirmed by actual observations made during 1927 and 1928 (May to July) at Sialkot, Rohtak and Lyallpur (Table I). An examination of flower-buds, flowers and green bolls was carried on, and it was observed that even when a fairly large supply of flower buds, flowers and green bolls was available, the pest was absent during May and June, and it was only during the last week of July that a very mild attack was noticed in 1927 at Sialkot and in 1928 at Lyallpur. In the former case only 0·4 per cent. of the bolls were attacked and in the latter only 0·6 per cent. It therefore seems very likely that the first brood of 'worms' that appears in the cotton fields is the progeny of moths emerging in July and the beginning of August.

TABLE I.

The Attack of Pink-Bollworm on ratoon cottons.

Locality	Month	Flower-buds		Flowers		Green bolls	
		Number examined	Per-centage attack	Number examined	Per-centage attack	Number examined	Per-centage attack
	1927.						
Sialkot	May	256	0	0	0	..	..
	June	886	0	81	0	72	0
	July	492	0	157	0	257*	0·4
	1928.						
	May	311	0	70	0	15	0
	June	581	0	242	0	122	0
	July	835	0	594	0	343	0
	1927.						
Rohtak	May	54	0	18	0	43	0
	June	46	0	56	0	44	0
	July	405	0	403	0	321	0
	1928.						
	May	56	0	40	0	22	0
	June	227	0	125	0	48	0
	July	103	0	90	0	84	0
	1927.						
Lyallpur	May	312	0	64	0	175	0
	June	1,346	0	308	0	4	0
	July	609	0	339	0	85	0
	1928.						
	May	45	0	30	0	5	0
	June	249	0	142	0	54	0
	July	100	0	396	0	319*	0·6

Figures marked (*) are those for the fourth week of July.

Emergence of moths.

It has been observed that the emergence of 'short-cycle' moths stops in January and that of the 'long-cycle' moths starts in April and continues till November with the greatest rush during July and August. The short-cyclers emerging up to January are not able to carry on the species because of the absence of food plants. The long-cyclers emerging from April to June are in the same position.

Longevity of P. gossypiella, Saund., moths.

It may be argued that the moths emerging from April to June may live till the end of July and start infestation. To settle this point observations on the longevity of moths were started in April 1928 and continued till November. Newly emerged moths were kept in the verandah of the laboratory at Sialkot. Dilute honey was supplied but the moths were not seen to feed. In all 3,895 moths were kept under observation, and it was noticed that over 84 per cent. of the moths died by the 6th day and about 13 per cent. more by the 9th day. After the 9th day only 2·5 per cent. survived, and on the 26th day there was only 0·02 per cent. living (Table II). Willcocks [1916] gives the maximum length of the life of *P. gossypiella*, Saund., moths as 31 days, and states that no difficulty has been experienced in keeping them in cages for about a fortnight. Busck [1917] states that under most favourable conditions in a cool place, supplied with water, some of the moths were kept alive for 32 days, but the majority died

TABLE II.

The length of the life of Platyedra gossypiella *moths bred at the field laboratory, Sialkot.*

Month, 1928	The number of moths under observation	The number of days for which the moths survived																		
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	17	20	22	24	26
April . .	300	17	39	54	47	42	42	26	26	6	1	0	0	0	0	0	0	0	0	0	0
May . . .	875	89	178	143	144	101	91	58	37	21	10	2	1	0	0	0	0	0	0	0	0
June . .	731	48	118	131	116	110	78	55	42	26	3	2	2	0	0	0	0	0	0	0	0
July . . .	1,408	216	30	270	218	144	111	90	34	17	8	0	0	0	0	0	0	0	0	0	0
August . .	466	6	70	68	70	63	46	30	18	5	0	0	0	0	0	0	0	0	0	0	0
September .	24	3	4	5	3	3	3	2	1	0	0	0	0	0	0	0	0	0	0	0	0
October . .	106	7	15	19	18	19	9	8	2	4	0	2	0	1	1	1	0	0	0	0	0
November . .	45	0	10	0	7	0	6	6	0	1	3	0	0	0	1	1	1	2	4	2	1
GRAND TOTAL .	3,895	416	734	690	623	482	386	25	160	80	25	6	3	1	2	2	1	2	4	2	1
Calculated per 100 moths .	100	10·6	18·8	17·7	15·9	12·3	9·9	7·1	4·1	2·1	0·6	0·1	0·7	0·02	0·05	0·05	0·02	0·05	0·1	0 05	0·02

within 20 days. Fullaway [1909] states that in Hawaii the average life of *P. gossypiella,* Saund., moths ranges from 10 to 15 days, and according to Guenther [1925] the adult moths lived in captivity for 14 days. Garcia [1925] records the life of the moth as 4 to 20 days in dry surroundings and up to 36 days under humid conditions. In the course of some recent observations carried on by the Min. Agric. Egypt, Entomological Section [1926], it was found that the adult Pink-Bollworms could live as long as 50 days during spring.

It is not possible to obtain definite data regarding the longevity of these moths under natural conditions, but from the observations made one is led to believe that in most parts of the Punjab—with high temperature and low humidity—a female moth emerging during April to June is not likely to survive till August.

Further, the cotton bolls, which constitute the main food of Pink-Bollworm, do not appear in sufficient numbers before August, and even if the moths emerging before July are capable of starting infestation, their progeny will be unable to survive for want of suitable food material. It is, therefore, maintained that the moths emerging up to the end of June and possibly those emerging in the beginning of July are of no consequence as sources of infestation. The moths emerging after that date are undoubtedly of great importance.

Progress of attack.

Although the attack starts in August, yet, even in tracts where Pink-Bollworm is a serious pest, it is only in September that the insect is present in appreciable numbers. The increase in numbers is very rapid during October and the first half of November. After the middle of November hibernation sets in, and no increase is generally possible. This, however, is the most important period so far as the infestation of the next year's crop is concerned, because by this datemost of the caterpillars have entered the ' long-cycle '.

About the end of the season (December) all the bolls present on plants may be infested, many of them containing more than one caterpillar, but it must be borne in mind that the higher percentage of infestation during December does not mean an actual increase in the Pink-Bollworm population. It is merely the result of a rapid fall in the population of bolls present at this time.

IV. The Winter-quarters of the ' long-cycle' Caterpillars.

After the cotton picking is over the long-cycle caterpillars may be distributed to the following situations :—

(A) In the *kapas* (seed-cotton) picked and carried away from the fields.

(1) *To the villagers' home.*—As most of the cotton crop in the Punjab is harvested in November and December, the long-cycle caterpillars are

first carried with *kapas* into the villages. Most of this *kapas* is, however, taken out of the villages to the markets, only small quantities being left for local use (see below).

(2) *To the ginning factories.*—Formerly the cotton was largely ginned by means of hand gins, which practice still continues on a small scale, but at present the cotton is mostly ginned at the ginning factories established throughout the cotton districts of the Punjab. Thus from villages a very large portion of the harvested crop finds its way to the ginneries where the crop is first spread out to dry, then cleaned, and finally ginned. The cleaning operation of *kapas* in the ginning factories is often done by means of a machine popularly known as " *Jhamba* " or " Opener ". During this process most of the caterpillars resting in the lint or in loosely united double-seeds get disturbed and creep out of their cocoons. The number of such caterpillars is at times very high. At places like Rohtak, where this insect is a serious pest, they may be seen in thousands. After ginning the caterpillars may be found :—

(*a*) *in patti**.—Some of these ' free ' caterpillars drop down and fall prey to common *myna* and crows, but a large proportion remains in heap of *patti* that accumulates under the " opener." These caterpillars hibernate in this material.

(*b*) *in seed-stores.*—After the cotton is ginned the Pink-Bollworms in the seed-worms are removed to the stores, and may be :—

(i) carried with seed to other provinces and even to other countries (Appendix II),

(ii) crushed to death while oil is being extracted from cotton seed,

(iii) left in seed in *mandies* and stores of ginning factories, or

(iv) carried back by the cultivators to villages in the seed required for feeding cattle and for sowing.

(B) LEFT BEHIND IN THE FIELDS.

(1) *In bolls on cotton sticks* :

(*a*) *left standing in the fields.*—Quite often cotton sticks are left standing in the fields for a considerable time after the cotton harvest, and Pink-Bollworms continue to find shelter in the bolls on these sticks.

(*b*) *cut and removed.*—Sooner or later the cotton sticks are cut and removed, and a fairly large number of attacked bolls remain attached to these sticks. These sticks (vernacular name *manchitti*) are either heaped in the fields or taken to villages. Sometimes they are even brought to the towns for use as fuel.

* Dried leaves and other trash.

(2) *In bolls and cotton seed dropped on the soil* :—

(*a*) fallen bolls lying mostly on the surface of the soil,

(*b*) fallen bolls which get partly buried under ground,

(*c*) bolls which are carried into the soil by rats.

(3) *Pupating in the soil.*—A major portion of the resting caterpillars remain under natural conditions inside the bolls in which they have fed, but in a few cases the caterpillars leave the bolls and creep into the soil. This, however, does not seem to be very common and in spite of our careful examination of the soil of a large number of cotton fields at Sialkot (during 1928), it was not possible to find in the soil more than one living and two dead Pink-Bollworms, and a dead pupa.

Attention may be drawn to similar observations made by King and Giffard [1924] in the Sudan, and Williams [1924] in Egypt, who while reviewing the resting quarters of *P. gossypiella*, Saund., have enumerated all the above-mentioned situations in which the hibernating caterpillars may be found.

Thus the possible places where the Pink-Bollworm passes the period between one cotton crop and the subsequent one are :—

(A) In fields	1. Bolls on plants left standing after harvest.
	2. Fallen bolls and *kapas* lying on the surface of the soil.
	3. Bolls and *kapas* lying underground.
(B) In villages	4. Bolls on sticks stored for fuel.
	5. *Kapas* and cotton seed.
	i. in villagers' homes.
	ii. with petty shopkeepers.
(C) In ginneries	6. *Kapas* and cotton-seed.
	7. Low grade cotton and heaps of *patti*.
(D) In stores	8. Ginned seed.

These places may form reservoirs for the infestation of the next cotton crop.

V. The Hibernating Pink-Bollworms and their surroundings.

To study the fate of hibernating caterpillars under different situations, extensive observations were made during 1926 to 1929 at Lyallpur, Rohtak and Sialkot. The results of these observations are dealt with in the following pages.

(1) The Fate of Pink-Bollworms in Bolls left on the Cotton plant after Harvest.

The number of hibernating caterpillars in bolls on cotton sticks.—After the final cotton picking a large number of bolls which are immature or have not produced pickable cotton is left on the plants. In case of an infested crop these bolls often stock a very large population of the resting caterpillars. It will be seen from the statement given below that even in January the bolls present on cotton sticks harbour a number of hibernating caterpillars, in some cases as many as 75 per 100 plants:—

Locality	Number of Pink-Bollworms from bolls on 100 plants in January		
	1927	1928	1929
Lyallpur	4	5	5
Rohtak	47	35	75
Sialkot	48	12	20

Disposal of cotton sticks.—The general practice followed by the peasants in the Punjab is to uproot cotton sticks during December to February. In those fields in which *senji* (*Melilotus parviflora*) is sown, and in a few cases even otherwise, the sticks are allowed to stay till as late as August. This has been established by actual observations carried out in the fifteen villages in three different districts—Sialkot, Rohtak and Lyallpur (Table III). It has been further observed that the date of cutting cotton sticks varies in different tracts of the Punjab. In the South-Eastern Punjab, where the crop is over by the end of November, the sticks are generally cut and removed in November and December. On the other hand, in the Canal Colonies, where the crop continues till the end of December or even the beginning of January in case of American cottons, the cutting down of the cotton sticks is delayed till January or even February. Although this is the general practice, yet instances of the previous year's cotton sticks standing in the fields till August are not uncommon.

TABLE III.

Dates on which cotton sticks were removed by cultivators during 1928-29.

District	Village	Number of cultivators	Area in acres under cotton	Area in acres from which cotton sticks were removed during different months									
				Nov.	Dec.	Jan.	Feb.	March	April	May	June	July	Aug.
Lyallpur	Chak 279	10	113½	0	0	48½	63	0	0	2	0	0	0
	Chak 207	8	19¼	0	0	16½	2¼	0	0	½	0	0	0
	Chak 220	14	95½	0	0	53	42½	0	0	0	0	0	0
	Chak 213	14	154½	0	0	116½	15	16½	0	2	2	2	½
	Chak 122	25	208½	0	0	52	88	57	3½	0	1	4½	2½
	Total	71	591¼	0	0	286½	210¾	73½	3½	4½	3	6½	3
Rohtak	Garhi	68	154	74½	78½	1	0	0	0	0	0	0	0
	Dobh	70	31	20	11	0	0	0	0	0	0	0	0
	Singhpura	71	132	123	9	0	0	0	0	0	0	0	0
	Manah	30	49½	35	12	0	0	0	0	0	0	2½	0
	Sunderpura	98	181	79	99	0	0	0	0	0	0	3	0
	Kanehli	22	42½	42½	0	0	0	0	0	0	0	0	0
	Total	359	590	374	209½	1	0	0	0	0	0	5½	0
Sialkot	Fatehgarh	40	35¾	1½	4½	7½	14½	7	¾	0	0	0	0
	Ramgarha	14	11¼	0	0	3¼	3½	4½	0	0	0	0	0
	Raipur	47	62¼	0	4½	37	19½	1¼	0	0	0	0	0
	Ugoki	60	67¼	0	3¾	32½	21	9¾	¼	0	0	0	0
	Total	161	176½	1½	12¾	80¼	58½	22½	1	0	0	0	0

The fate of bolls on cotton sticks.—During 1929 observations were made to find out the number of bolls which remained on the cotton sticks from January to April. Ten localities in ten different districts in the Punjab were selected, and at each place the number of bolls present on one hundred sticks left standing in the fields was counted. For each locality three observations were made, one observation in each of the following months—January, February—March and April. It has been observed (Table IV) that by the middle of April most of the bolls on the plants left standing in the fields had either fallen to the ground or had been eaten up by flocks of goats and sheep that are often let into the fields to graze. There were, however, certain instances of cotton fields in which a fair number of bolls was present on the sticks in April, but such cases were very rare.

Conclusions.—After the last cotton picking, the bolls which do contain a large number of Pink-Bollworms are left behind. These bolls, however, are likely to be shed sooner or later. Thus, practically all over the Punjab, sticks left standing in the fields hardly bear a boll after April. Even, if present, the number of such bolls is so small that this source of infestation is of no consequence. (The fate of Pink-Bollworm in the shed bolls is dealt with below.)

TABLE IV.

Presence of bolls on cotton plants left standing in the fields after cotton harvest of 1928 (observations made in 1929).

Vicinity	Number of bolls on 100 cotton plants		
	January	February and March	April
1. Gujranwala	567	176	31
2. Amritsar	351	167	0
3. Jullundhur	320	173	0
4. Hoshiarpur	178	109	22
5. Ludhiana	189	114	43
6. Ambala	170	142	0
7. Karnal	167	131	0
8. Palwal (Gurgaon)	158	90	0
9. Sirsa (Hissar)	185	100	21
10. Ferozepore	275	120	31

(2) THE FATE OF PINK-BOLLWORMS IN BOLLS AND *KAPAS* LYING ON THE SURFACE OF THE SOIL.

The number of hibernating Pink-Bollworms present in 'shed material' after harvest.—A large number of bolls and quantities of *kapas* fall down from the plants through various causes, particularly during picking and during the time the sticks are left standing after harvest (as stated above), or at the time of cutting and removing sticks from the fields. Observations were made in January 1927, 1928 and 1929 to find out the number of resting Pink-Bollworms in this 'shed-material'. An area containing 100 plants was marked off for each observation, and all the shed-material collected and examined. The results of these observations are summarised below :—

Locality	The number of Pink-Bollworms in shed material from 100 plants in January		
	1927	1928	1929
Lyallpur	2	2	1
Rohtak	27	48	22
Sialkot	237	47	3

It may be mentioned that the number of resting caterpillars depends on the intensity of attack, the number of bolls formed and the amount of shedding and various other factors and that it naturally varies from year to year, but in case of infested localities such bolls contain a large population of Pink-Bollworms.

The quantity of shed-material during different months.—The amount of 'shed-material' found during different months varied. Generally it was found in abundance till March and April, but later on the quantity diminished considerably. It was, however, possible to find some of this material lying in the fields as late as July or August. The successive reduction in the quantity of this 'shed-material' from January onward may be accounted for by the facts that zemindars allow sheep and goats to graze in the old cotton fields, and the fallen bolls and other debris of the cotton crop lying on the ground are eaten up or get trampled under feet and buried under ground. This practice is of great utility in reducing the chances of the Pink-Bollworms in fallen bolls reaching maturity. Again when the cotton fields are ploughed, some of the material originally lying on the surface of the soil gets buried and, therefore, the material lying on the ground diminishes.

The influence of agricultural operations on Pink-Bollworms present in the shed-material.—The agricultural operations which a cotton field is subjected to after cotton picking play an important role in influencing the fate of Pink-Bollworms found in the 'shed-material' lying on the surface of the soil. In the Punjab after cotton picking, the fields may be left fallow or sown with some other crop. The

rotations commonly practised in the Punjab are given in Appendix III. From the study of the data collected it will be seen that in the Punjab the cotton may be followed by one of the following crops :—Wheat (*Triticum sativum*), *juar* (*Andropogon Sorghum*), *guara* (*Cyamopsis psoraboides*), sugarcane (*Saccharum officinarum*), maize (*Zea mays*), cotton (*Gossypium* sp.) and *senji* (*Melilotus parviflora*). Wheat sometimes immediately follows cotton (*desi*) especially in the well-irrigated areas, where intensive farming is practised, but generally it follows cotton after a fallow. In the latter case, which is the commonest (over 80 per cent.) rotation all over the Punjab, the land is in a perfectly dry condition until July and August, when the monsoon (rainy season) starts in the province. When *juar* and *guara* follow cotton, the land usually remains dry till April or May when it is irrigated and ploughed, and seed sown in May and June. In case of sugarcane or cotton following cotton, which is a rare practice, the land after it has been cleaned of its cotton sticks in December and January is immediately watered and ploughed, and sugarcane is sown from March to April, and cotton in April or even later. When maize follows cotton, the fields remain fallow for about six months. Maize is ordinarily sown in the plains late in June or early July and sometimes towards the beginning of August as in the Canal Colonies. Thus the period of fallow between the removal of cotton sticks and maize sowing is different at different places. *Senji* is sown from October to November while cotton sticks are still standing in the fields, and the crop remains on the ground till February or March.

This brief outline of the agricultural practice (Table V) shows that land remains fallow from January to October in case of wheat, from January to April in case of sugarcane and cotton, from January to June in case of maize and from March till the sowing of another crop in case of *senji*. Thus it will be seen that during April and May, when the hot season begins in the Punjab, the cotton fields of the previous year are mostly ' uncovered ' and in a few cases only have germinating crops such as sugarcane, *juar* or cotton in them.

During the period the land is lying fallow, or is without a crop, the surface of the soil and everything lying on it is fully exposed to sun-heat except for the shade of a few weeds growing here and there.

Hibernating caterpillars exposed to sun-heat.—In order to ascertain what happens to the caterpillars in the bolls lying on the ground, observations were carried out at Rohtak, Sialkot and Lyallpur during the years 1927 and 1928. At each locality twelve plots, each of hundred plants, were kept for this observation. They were kept fallow after the cotton harvest. The sticks from these plots were cut on 31st December, and from that date till the date of the examination the shed-material was left untouched on the ground. The material from Plot No. 1 was examined in January, of Plot No. 2 in February and so on (Table VI

TABLE V.

The condition of cotton fields after cotton harvest.

Crop following cotton	Rotation practice.	Irrigated areas		*Barani* areas		State of fields in April and May	Remarks
		Preparatory tillage	Period of watering for seed-bed preparation and sowing	Preparatory tillage	Period of watering for seed-bed preparation and sowing		
	Per cent.						
Wheat . .	80	July to September.	October and November.	End of June to end of October.	October and November.	Fallow . .	Occasionally wheat immediately follows cotton, especially in well-irrigated areas, where intensive farming is practised, in which case full-grown wheat crop will be standing in the fields during April and May, but this is exceedingly rare.
Senji . .	10	*Nil* .	September and October.	...	...	Fallow . .	
Sugarcane .	6	January and February.	Middle of February to middle of March.	January and February.	Middle of February to middle of March.	With germinated crop.	
Juar and *Guara*	2	April to July.	April to July	End of June to middle of August.	End of June to middle of August.	Often fallow, some times with germinated crop.	
Maize . .	2	June . .	June and July	...	...	Fallow . .	
Cotton (annual and perennial)	rare	January to March.	April and May	...	...	With germinated crop.	When ratooned the stubbles remain in the fields throughout the year and these fields receive very little watering.

cols. 6, 11, 16). The figures of Table VI are re-arranged in Table VII so as to show the relation of mortality of the Pink-Bollworms hibernating in the fallen bolls with that of the maximum temperature of the air. It was found that up till the end of February most of the Pink-Bollworms resting in fallen bolls survived and the mortality did not exceed 31 per cent. During March and April a large number of caterpillars began to die and by the beginning of May the mortality had reached cent per cent. This was because the temperature of bolls lying on fallow lands fully exposed to the rays of the sun rose sufficiently high to kill all the resting Pink-Bollworms. It may be mentioned that at the shade temperature of about 104°F. (40°C.), the bolls exposed to direct sun-heat in the open are subjected to a temperature much higher, the temperature of the black bulb thermometer being about 162°F. (72°C.). According to King and Giffard [1924, 1] the fatal temperature for the larvæ in bolls lying on the ground is reached when the shade temperature is 104°F. These two sets of observations made in two different countries leave no ground for doubt that when the temperature in shade is higher than 104°F. and the bolls are fully exposed to the sun, the resting caterpillars in such bolls must die.

Temperature attained by the infested bolls exposed to sun-heat.—With a view to ascertain that Pink-Bollworms resting in shed bolls die through effects of sun-heat, the following experiments were performed. A large number of infested bolls, obtained from Rohtak and Sialkot, were exposed in April and May to sun-heat at Lyallpur. Each sample of bolls was spread directly on the soil in a single layer and exposed to the sun from 10 A.M. to 4 P.M. In all fourteen observations were made, in each of these, two hundred and fifty bolls were exposed to sun-heat (Table VIII). The temperature of the bolls was taken at intervals of one hour by placing the bulb of the thermometer on a central boll of the heap and putting some more bolls round the heap. In this position the thermometer was allowed to remain for about five minutes and the temperature recorded.

The results show (Table VIII) that out of fourteen exposures of the attacked bolls to the sun during April and May, it was on two occasions only, *i.e.*, 6th and 29th April, that the temperature of the bolls did not rise higher than 50°C. (122°F.) but remained at 47°C. (116·7°F.) and 49°C. (120·2°F.), giving respectively 62·4 and 78·0 percentage mortality among the caterpillars. In all other cases the temperature of the bolls reached 50°C. or even higher and no caterpillar was found to have survived. A reference to Table X will show that sun-heat is fatal for caterpillars resting in fallen bolls, when the temperature goes above 50°C. Even at a slightly lower temperature most of the caterpillars die, only a few surviving.

Regarding the temperature attained by dead bolls exposed to direct sun-heat and its relations to the maximum air temperature in shade, it was seen that the bolls lying on the ground during April and May attained the temperature of 50°C.—

TABLE VI.

Pink-Bollworms found in picked kapas, *in shed bolls, and in bolls on stored sticks, from 12 plots each of 100 plants, at Rohtak, Sialkot, and Lyallpur, during 1927-28.*

NOTE :—One *tola* = 0·415 Ounce.

Plot No.	The month when the material was examined	Rohtak					Sialkot					Lyallpur				
		Yield of *kapas* in *tolas*	Number of living Pink-Bollworms found				Yield of *kapas* in *tolas*	Number of living Pink-Bollworms found.				Yield of *kapas* in *tolas*	Number of living Pink-Bollworms found			
			In *kapas* picked and stored	In bolls on stored sticks	In fallen bolls (shed material)	Total		In *kapas* picked and stored	In bolls on stored sticks	In fallen bolls (shed material)	Total		In *kapas* picked and stored	In bolls on stored sticks	In fallen bolls (shed material)	Total
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
	Year 1927.															
1	January	160	563	44	26	633	417	2,120	44	237	2,401	36	32	1	4	37
2	February	206	605	33	7	645	511	2,244	30	320	2,594	52	43	3	42	88
3	March	152	469	54	1	524	463	2,060	56	138	2,254	73	47	1	11	59
4	April	167	574	36	0	610	224	1,602	38	9	1,649	42	33	4	1	38
5	May	170	466	19	0	485	348	1,437	21	0	1,458	46	20	1	0	21
6	June	149	373	12	0	385	284	664	0	0	664	33	19	1	0	20
7	July	163	167	5	0	172	266	404	0	0	404	39	8	0	0	8
8	August	180	69	0	0	69	422	95	0	0	95	40	2	0	0	2
9	September	175	35	0	0	35	432	5	0	0	5	52	2	0	0	2
10	October	223	8	0	0	8	525	2	0	0	2	104	4	0	0	4
11	November	190	0	0	0	0	422	0	0	0	0	110	0	0	0	0
12	December	170	0	0	0	0	375	0	0	0	0	50	0	0	0	0

Pink-Bollworms found in picked kapas, *in shed bolls, and in bolls on stored sticks from 12 plots each of 100 plants, at Rohtak, Sialkot, and Lyallpur, during 1927-28*—contd.

Plot No.	The month when the material was examined	Rohtak					Sialkot					Lyallpur				
		Yield of *kapas* in *tolas*	Number of living Pink-Bollworms found				Yield of *kapas* in *tolas*	Number of living Pink-Bollworms found				Yield of *kapas* in *tolas*	Number of living Pink-Bollworms found			
			In *kapas* picked and stored	In bolls on stored sticks	In fallen bolls (shed material)	Total		In *kapas* picked and stored	In bolls on stored sticks	In fallen bolls (shed material)	Total		In *kapas* picked and stored	In bolls on stored sticks	In fallen bolls (shed material)	Total
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
	Year 1928.															
1	January . .	191	711	35	48	794	404	1,543	12	46	1,601	257	161	5	3	169
2	February . .	145	425	25	15	465	320	1,391	2	29	1,422	282	69	4	3	76
3	March . .	142	438	16	2	456	354	1,437	5	12	1,454	294	73	0	2	75
4	April . . .	128	327	18	2	347	345	1,344	3	1	1,348	352	80	4	0	84
5	May . . .	132	364	6	0	370	406	1,163	3	0	1,666	281	55	2	0	57
6	June . . .	151	693	3	0	696	337	1,100	0	0	1,100	174	49	3	0	52
7	July . . .	100	340	1	0	341	426	833	0	0	833	137	27	5	0	32
8	August . .	105	31	0	0	31	405	166	0	0	166	147	13	0	0	13
9	September . .	83	13	0	0	13	423	34	0	0	34	217	10	0	0	10
10	October . .	93	3	0	0	3	495	15	0	0	15	208	10	0	0	10
11	Nvember . .	93	1	0	0	1	414	1	0	0	1	225	12	0	0	12
12	December . .	85	0	0	0	0	428	4	0	0	4	362	20	0	0	20
	Calculated as if the yield per plot is 500 *tolas* of *kapas*. *Year 1927.*															
1	January . .	...	1,759	138	81	1,973	...	2,542	53	284	2,839	...	444	14	55	513
2	February . .	...	1,469	80	17	1,566	...	2,195	30	313	2,538	...	413	29	404	846

3	March . . .	...	1,543	178	3	1,724	...	2,225	60	149	2,434	...	322	7	75	404
4	April . . .	...	1,718	108	0	1,826	...	1,899	45	10	1,944	...	393	48	12	453
5	May . . .	...	1,370	56	0	1,426	...	2,064	30	0	2,094	...	217	11	0	228
6	June . . .	...	1,252	40	0	1,292	...	1,169	0	0	1,169	...	288	15	0	303
7	July . . .	...	513	15	0	528	...	759	0	0	759	...	103	0	0	102
8	August . .	..	192	0	0	192	...	113	0	0	113	...	25	0	0	25
9	September . .	...	100	0	0	100	...	6	0	0	6	...	19	0	0	19
10	October . .	...	18	0	0	18	..	2	0	0	2	...	19	0	0	19
11	November . .	...	0	0	0	0	...	0	0	0	0	...	0	0	0	0
12	December . .	...	0	0	0	0	...	0	0	0	0	...	0	0	0	0
	Year 1928.															
1	January . .	...	1,862	91	126	2,079	...	1,909	15	57	1,981	..	313	9	6	328
2	February . .	.	1,466	17	10	1,493	...	2,174	3	45	2,222	...	122	7	5	134
3	March. . .	...	1,543	56	7	1,606	...	2,030	7	17	2,054	...	124	0	4	128
4	April . . .	...	1,385	76	9	1,470	...	1,948	4	2	1,954	...	114	6	0	120
5	May . . .	...	1,379	23	0	1,402	..	1,432	4	0	1,436	...	98	4	0	102
6	June . . .	..	2,295	10	0	2,305	...	1,632	0	0	1,632	..	141	9	0	150
7	July . . .	...	1,700	5	0	1,705	...	978	0	0	978	...	98	18	0	116
8	August . .	...	148	0	0	148	...	205	0	0	205	...	44	0	0	44
9	September . .	...	78	0	0	78	...	40	0	0	40	...	23	0	0	23
10	October . .	...	16	0	0	16	...	19	0	0	19	...	24	0	0	24
11	November . .	...	5	0	0	5	...	1	0	0	1	...	27	0	0	27
12	December . .	...	0	0	0	0	...	5	0	0	5	..	28	0	0	28

Remarks.—In each plot the number of plants under observation was only 100 and so great variation was noticed regarding the yield of *kapas* from different plots. From each plot *kapas* was picked weekly from September to December and separately stored in bags, the cotton sticks were cut on 31st December and placed on the roof of the laboratory, and the fallen bolls were left on the ground undisturbed.

TABLE VII.

Mortality of Pink-Bollworms in shed material lying on fallow lands, taken from 100 plants every month.

Month of examination	Locality	(Shed-material) Number of dried bolls, buds and flowers examined		Number of Pink-Bollworms found						Absolute maximum shade temperature (F.) during the period of first January to the date of examination	
				Total number found		Number found dead		Percentage mortality			
		1927	1928	1927	1928	1927	1928	1927	1928	1927	1928
January	Lyallpur	314	177	4	4	0	1	0	25·0	77·5	70·0
	Rohtak	712	846	27	52	1	4	3·7	7·7	78·8	70·2
	Sialkot	917	1,068	249	52	12	6	4·8	11·5	73·9	72·0
February	Lyallpur	587	1,237	47	3	5	0	10·6	0	77·5	74·0
	Rohtak	334	435	10	17	3	2	30·0	11·8	80·6	85·0
	Sialkot	2,183	903	352	42	32	13	9·1	31·0	73·9	79·0
March	Lyallpur	775	570	11	4	1	2	9·9	50·0	77·7	88·0
	Rohtak	564	597	6	18	5	16	83·3	88·8	93·2	96·0
	Sialkot	1,901	1,249	174	29	36	17	20·7	58·6	91·9	90·0
April	Lyallpur	1,688	467	2	0	1	0	50·0	..	94·4	104·0
	Rohtak	801	239	27	58	27	56	100·0	96·5	97·7	..
	Sialkot	2,153	900	85	14	76	13	89·4	92·9	103·7	102·0
May	Lyallpur	1,456	291	0	0	0	0	..	..	104·3	110·0
	Rohtak	757	54	25	28	25	28	100·0	100·0	104·0	115·0
	Sialkot	1,715	775	81	8	81	8	100·0	100·0	111·7	115·0
June	Lyallpur	440	219	2	0	2	0	100·0	..	114·6	111·0
	Rohtak	839	198	30	36	30	36	100·0	100·0	112·1	114·0
	Sialkot	1,084	632	39	10	39	10	100·0	100·0	111·9	115·0
July	Lyallpur	69	271	0	0	0	0	..	..	114·6	111·0
	Rohtak	299	..	13	23	13	23	100·0	100·0	112·1	108·0
	Sialkot	434	199	12	3	12	3	100·0	100·0	111·9	115·0

which is fatal to the resting caterpillars—when the air temperature in shade was 35°C. (95°F.) to 40°C. (104°F.). It may be pointed out that at 40°C. of air temperature or higher, the temperature fatal for the resting caterpillars is invariably reached. Below this the fatal temperature may or may not be attained. It may further be added that in April and May the air temperature in shade is 40°C. or more in all the cotton growing districts of the province.

Further it may be of interest to record that the intensity of solar radiation also plays an important part in bringing about the destruction of caterpillars resting in fallen bolls. The question is being investigated.

TABLE VIII.

Mortality of Pink-Bollworms resting in bolls exposed to sun-heat from 10 a.m. to 4 p.m. during April and May at Lyallpur.

Date of exposure	Maximum temperature in centigrade			Pink-Bollworms after exposures			Remarks
	Shade	Sun		Number living	Number dead	Percentage mortality	
		of exposed bolls	of black bulb thermometer				
Year 1928.							
April . . 6	37·7	47·0	64·7	32	53	62·4	
,, . 9	33·8	..	...	61	0	0	Control*
,, . . 10	35·5	49·8	67·2	0	53	100·0	
,, . . 13	40·0	50·5	71·1	0	13	100·0	
,, . 20	...	49·0	54·4	18	64	78·0	Windy day
,, . . 23	34·4	54·5	68·8	0	75	100·0	
,, . . 24	37·2	..	...	92	0	0	Control*
,, . . 26	36·6	59·5	65·5	0	80	100·0	
May . . 5	38·8	69·5	72·2	0	77	100·0	
,, . . 7	43·1	...	...	56	13	18·8	Control*
,, . . 7	43·1	66·0	74·1	0	87	100·0	
,, . . 9	43·3	67·5	77·4	0	55	100·0	

Mortality of Pink-Bollworms resting in bolls exposed to sun-heat from 10 a. m. to 4 p. m. during April and May at Lyallpur—contd.

Date of exposure	Maximum temperature in centigrade			Pink-Bollworms after exposures			Remarks
	Shade	Sun		Number living	Number dead	Percentage mortality	
		of exposed bolls	of black bulb thermometer				
Year 1928 - contd.							
May . . 12	38·6	59·0	71·7	0	72	100·0	
,, . . 17	40·2	67·0	71·1	0	81	100·0	
,, . . 21	42·0	59·8	73·8	0	72	100·0	
,, . . 25	43·0	60·2	75·0	0	69	100·0	
,, . . 29	44·0	55·0	70·5	0	58	100·0	
,, . . 30	43·6	..	..	63	11	14·9	Control*

NOTE.—Bolls kept as control (*) were placed in wire gauze cages in the laboratory.

During May 1929, experiments were performed to find out the time a boll exposed to sun-heat would take to attain an internal temperature of 50°C. at a known air temperature with a known solar radiation. The internal temperature of the boll was recorded by thermo-couple arrangement. An hourly (8 A.M. to 2 P.M.) record of the internal temperature of the boll exposed to the heat of the sun, temperature of the air in shade and that of the black bulb thermometer was maintained (Table IX).

It appears that a fallen boll exposed to direct sun-heat may attain a temperature (50°C.) fatal to the Pink-Bollworms after an hour's exposure, and in some cases as early in the day as 9 A.M., but this temperature was invariably attained by 12 noon, *i.e.*, after four hours' exposure. From 12 noon to 2 P.M. the temperature of the boll went on increasing and in most cases it reached above 60°C. at which the death of the Pink-Bollworms is almost instantaneous. It was observed that the temperature of the fallen bolls was always higher than the temperature of the air in shade, and the difference varies with the hours of the day, it being 5-15°C. from 8 to 9 A.M., and 10-33°C. from 10 A.M. to 2 P.M. It was further observed that the temperature of the fallen bolls depended on two variable factors, the temperature of the air and solar radiation.

The influence of irrigation on temperature of fallen bolls.—In this connection it is necessary to consider the influence of irrigation on the temperature of the bolls lying in the fields. In Table X is given the maximum screen temperatures of air

before and after irrigation in a cotton field and in a grassy plot (Lyallpur), which show that as a result of each watering the maximum temperature of the air was lowered by 1 to 3°F. It was further seen that this fall in temperature was often appreciable for only a day or so, and is therefore negligible. It may, however, be mentioned that as a result of each irrigation the bolls get wet and

TABLE IX.

The internal temperature of fallen bolls exposed to sun-heat recorded at Lyallpur during 1929.

Date	Particulars	Temperature (C.) recorded at						
		8 A. M.	9 A. M.	10 A. M.	11 A. M.	12 noon.	1 P. M.	2 P. M.
May 11th	Air in shade	31·0	35·5	37·6	40·2	41·0	41·6	41·9
	Bolls in sun	42·7	51·3	52·7	61·3	59·0	50·7	53·1
	Excess	11·7	15·8	15·1	21·1	18·0	9·1	11·2
May 23rd	Air in shade	..	..	37·2	37·2	38·7	39·5	40·0
	Bolls in sun	..	..	50·1	54·1	57·1	61·3	65·0
	Excess	..	..	12·9	16·9	18·4	21·8	25·0
May 27th	Air in shade	32·5	33·6	35·6	36·9	38·1	39·2	40·2
	Bolls in sun	37·3	41·7	45·1	46·4	51·3	58·4	61·2
	Excess	4·8	8·1	9·5	9·5	13·2	19·2	21·0
May 28th	Air in shade	..	35·0	36·2	38·4	39·8	40·7	41·6
	Bolls in sun	..	50·4	60·3	71·3	73·0	64·7	66·5
	Excess	..	15·4	24·1	32·9	33·2	24·0	24·9
May 29th	Black Bulb		59·9	69·1	71·6	75·3	76·0	76·4
	Air in shade	33·4	34·7	38·1	40·0	41·4	43·1	44·0
	Bolls in sun	42·2	48·6	57·5	65·9	61·6	69·1	66·9
	Excess	8·8	13·9	19·4	25·9	20·2	26·0	22·9

The internal temperature of fallen bolls exposed to sun-heat recorded at Lyallpur during 1929.

Dates	Particulars	Temperature (C.) recorded at						
		8 A. M.	9 A. M.	10 A. M.	11 A. M.	12 noon.	1 P. M.	2 P. M.
May 30th	Black Bulb .	57·8	59·7	67·7	71·8	73·9	75·0	76·0
	Air in shade .	34·8	37·2	38·9	40·7	43·0	43·9	44·8
	Bolls in sun .	40·9	49·2	58·6	64·2	62·3	62·7	62·4
	Excess . .	6·1	12·0	19·7	23·5	19·3	18·8	17·6
May 31st	Black Bulb .	..	57·2	63·8	68·3	71·3	73·0	75·0
	Air in shade .	33·6	34·3	35·5	37·1	38·0	38·5	39·6
	Bolls in sun .	42·6	43·4	49·7	48·5	56·6	59·4	65·8
	Excess . .	9·0	9·1	14·2	11·4	18·6	20·9	26·2

TABLE X.

Effect of irrigation on the air temperature of cotton field and grassy plot at Lyallpur.

Irrigation in cotton field				Irrigation in grassy plot			
Date (1928)	Maximum temperature of air in		Fall in temperature due to irrigation	Date (1928)	Maximum temperature of air in		Fall in temperature due to irrigation
	Cotton field	Grassy plot			Cotton field	Grassy plot	
March 11th . .	76.0	77·0		January 9th .	69·5	70·0	
	77·0*	79·0	1·0		71·5	71·0*	1·0
April 1st . .	81·5	81·5		January 26th .	58·5	60·0	
	80·5*	81·0	0·5		55·5	56·0*	1·0
April 25th . .	97·0	99·0		May 4th . .	98·9	100·0	
	89·0*	92·0	1·0		101·5	102·2*	0·6
May 25th . .	112·0	111·4		June 10th . .	100·0	101·0	
	109·8*	109·5	0·3		94·0	93·0*	2·0
June 24th . .	107·0	108·0		July 7th . .	96·8	98·0	
	105·7*	109·0	2·3		96·0	96·0*	1·2
July 14th . .	103·8	104·0		August 22nd .	102·5	107·0	
	106·5*	107·0	0·3		91·0	94·0*	1·5
August 13th . .	99·7	101·0		September 2nd .	77·0	79·0	
	96·8*	101·0	2·9		84·5	86·0*	0·5
September 24th .	98·8	100·0		October 8th . .	93·0	97·0	
	94·5*	99·0	3·3		95·3	97·0*	2·3
October 20th . .	95·0	96·0		November 2nd .	87·0	88·8	
	91·0*	95·0	3·0		90·5	91·2*	1·1
....	..	..	..	November 27th .	74·5	75·6	
....	..	..	..		69·0	68·7*	1·4

Temperature marked (*) is for the day following the date of irrigation.

then tend to rot, and are in certain cases completely rendered unfit for the resting Pink-Bollworms. If this fact be taken into account, the chances of the Pink-Bollworms successfully 'resting' in fallen bolls are reduced still further.

Conclusions.—Almost all the caterpillars resting in fallen bolls subjected to sun-heat even for one day during April and May, when the maximum temparature in shade is above 40°C. (104°F.), die. It may, therefore, be taken as established that under conditions prevailing in the Punjab, the bolls lying on the ground are not a source of danger to the new crop. It is just possible that in certain localities the resting caterpillars may be able to live longer than they would at other places, but the chances of their completely withstanding the high temperature in May and June, which in shade reaches 115°F. (46°C.) or even more (Appendix IV) in most of the districts in the Punjab, are very remote.

(3) The Fate of Pink-Bollworms in Bolls and Seeds buried under the Ground.

The quantity of material buried and the number of resting Pink-Bollworms.—It has been discovered that some of the infested bolls and *kapas* that drop off from the plants fall into cracks and crevices of the soil. Through ploughing up the land or through the fallen material getting trampled by the harvestors, flocks of sheep and goats, etc., some of the bolls or *kapas* get partially or totally buried.

To find out the quantity of material buried, observations were made from January to March 1929 at Sialkot, Rohtak and Lyallpur. In all sixteen fields (each about 625 square feet in area) were examined ; eight of these fields were ploughed and eight left unploughed (Table XI). In the unploughed fields the bolls dropped in cracks and those buried under soil were, on an average, about 18 per cent. of the bolls on the surface of the soil, and the total number of living Pink-Bollworms contained in the former was about 16 per cent. of the number contained in the latter. In the ploughed-up fields the bolls buried under soil were 40 per cent. of the bolls on the surface of the soil, and the total number of living Pink-Bollworms contained in the former was about 14 per cent. of the number contained in the latter. Thus the number of bolls buried in the soil was generally very small as compared to that lying on the surface of the soil. The reason for this is that the Punjab soil does not crack much. Thus while the average number of bolls obtained from an unploughed field (625 square feet area) was 288 (245 from surface of the soil, and 43 from soil cracks and under soil clods), it was only 83 (59 from surface of the soil, and 24 from soil cracks and buried in the soil) from ploughed-up fields. This shows that the quantity of the shed material found

TABLE XI.

Attack of Pink-Bollworm in bolls lying on the surface and buried in the soil during 1929.

Condition of the field	Month of examination	Locality	Bolls found from an area of 625 square feet					
			On surface of soil			In cracks and buried under ground		
			Number examined	Number of living Pink-Bollworms found	Number of Pink-Bollworms estimated per 100 bolls	Number examined	Number of living Pink-Bollworms found	Number of Pink Bollworms estimated per 100 bolls
Unploughed	January .	Lyallpur .	208	5	2	..	..	..
	February .	Lyallpur .	128	3	2	7	1	14
	,, .	Sialkot .	194	13	7	83	7	8
	,, .	Sialkot .	183	13	7	105	9	9
	,, .	Rohtak .	446	76	17	15	0	0
	,, .	Rohtak .	531	83	16	24	0	0
	March . .	Lyallpur .	97	2	2	7	1	14
	,, .	Sialkot .	172	17	10	103	14	14
..	..	Average .	245	26	11	43	4	9
Ploughed .	January .	Lyallpur .	139	3	2	6	1	16
	February .	Lyallpur .	73	3	4	5	0	0
	,, .	Sialkot .	32	4	12	72	5	7
	,, .	Rohtak .	46	15	33	10	0	0
	,, .	Rohtak .	58	21	36	14	0	0
	March . .	Lyallpur .	72	4	6	..	..	..
	,, . .	Lyallpur .	20	0	0	37	0	0
	,, . .	Sialkot .	29	5	17	79	4	5
..	..	Average .	59	7	12	24	1	4

during the period immediately following cotton harvest in the ploughed fields is approximately one-fourth of that found in the unploughed fields. It was further

noticed that the number of Pink-Bollworms found in the bolls lying under the surface of the soil was very low, never exceeding 14 per 100 bolls.

The influence of ploughing immediately after harvest.—These field observations have shown that while on the one hand, about 70 per cent. of the shed bolls are broken up (which later on rot and get destroyed) by ploughing up the fields immediately after cutting the cotton sticks, on the other hand, by this practice a number of bolls, etc., gets buried under soil, and the caterpillars resting in buried bolls escape the effect of sun-heat. Wilcocks [1916] comes to the same conclusion and states " the Pink-Bollworms in the bolls which are buried during the ploughing of the land, will be protected from possible natural enemies and it also seems probable that they will receive a great protection from sun-heat owing to intervening layer of soil. The degree of protection will, of course, depend on the thickness of the layer ".

Survival of hibernating Pink-Bollworms buried under ground.

In order to obtain definite information regarding the survival of the resting caterpillars which remain buried under ground during winter, eighteen different samples of damaged cotton bolls were buried in the soil at Lyallpur at the depth of two inches and four inches.

Each sample of fifty bolls was placed in a small fine meshed wire gauze cage. The cages were placed side by side in three different plots of land. Plot No. 1 was kept dry, Plot No. 2 was watered once a week, and Plot No. 3 was watered almost daily and was thus constantly wet. The bolls were buried in January 1928 and examined in May 1928. The results are presented in Table XII. A study of this table shows that mortality among the caterpillars resting in bolls buried in the

TABLE XII.

Mortality of Pink-Bollworms in bolls buried at depths of two inches and four inches in plots that received varying amounts of water.

(*Bolls were buried in January 1928 and examined in May 1928.*)

Plot number	Condition to which the plot was subjected	Depth to which bolls were buried	Number of bolls buried	Number of Pink-Bollworms found			Remarks
				Living	Dead	Percentage mortality	
1	Dry	Ins.					
		2	50	9	5	35·7	Received no artificial watering.
		2	50	0	0	..	
		2	50	2	2	50·0	
		Total	150	11	7	38·9	

TABLE XII—*contd.*

Mortality of Pink-Bollworms in bolls buried at depths of two inches and four inches in plots that received varying amounts of water—contd.

(Bolls were buried in January 1928 and examined in May 1928.)

Plot number	Condition to which the plot was subjected	Depth to which bolls were buried	Number of bolls buried	Number of Pink-Bollworms found			Remarks
				Living	Dead	Percentage mortality	
1—*contd.*	Dry	Ins. 4	50	3	4	57·1	
		4	50	0	1	100·0	
		4	50	0	0	..	
		Total	150	3	5	62·5	
2	Moist	2	50	1	6	85·7	Watered once a week.
		2	50	0	3	100 0	
		2	50	0	4	100·0	
		Total	150	1	13	92·9	
		4	50	2	5	71·4	
		4	50	0	5	100·0	
		4	50	0	4	100·0	
		Total	150	2	14	87·5	
3	Wet	2	50	0	3	100·0	Watered almost daily.
		2	50	0	2	100·0	
		2	50	0	8	100·0	
		Total	150	0	13	100·0	
		4	50	0	6	100·0	
		4	50	0	6	100.0	
		4	50	0	5	100·0	
		Total	150	0	17	100·0	
	Control	..	250	56	13	18·8	Kept in the laboratory.

soil depends on the depth to which the bolls are buried. There is greater survival near the surface than at greater depths. It is also seen that if the soil during winter is kept moist, the conditions for the buried caterpillars are less favourable than if the soil remains dry. Thus very few caterpillars survive at a depth of four inches under any conditions and when the soil is kept wet not a single one survives.

It may, however, be pointed out that the percentage of mortality among caterpillars as shown in Table XII, is far less than was actually the case. The reason for this is that the total number of caterpillars originally present in the bolls, as shown by the control, was as high as 27 per 100 bolls, but when the bolls were taken out for examination the number found was much less. It may, however, be said that there was very little chance of the caterpillars escaping, as the attacked bolls were buried inside the cages having wire gauze of very fine meshes. There can thus be only one possibility for the decrease in the number of worms, namely, that the missing caterpillars had died and disintegrated and, at the time of the examination of bolls, no trace of them was left. These results confirm those of Willcocks [1921] and Williams and Bishara [1925], that is, in bolls buried below thirty centimeters no caterpillars survive.

Conclusion.—As to the relative importance of the infested bolls buried in the soil in causing infestation to the growing crop, it is not yet possible to pronounce any definite opinion, but it seems very unlikely that under the Punjab conditions more than an occasional moth ever succeeds in emerging from the buried bolls after the month of June.*

(4) The Fate of Pink-Bollworms in Bolls, *Kapas*, etc., carried away by Rats.

Amount of cotton in rat-holes and number of caterpillars.

As already stated, some of the fallen bolls, as well as, *kapas* are carried by rats to their burrows situated not only in the cotton fields, but even in the adjoining fields. To discover as to what happens to the Pink-Bollworms in these places a large number of rat-holes were dug up during February-March at Lyallpur, Sialkot, Rohtak, Phillaur, and Ropar, and the material collected was examined (Table XIII). Of the 225 rat-holes explored at Lyallpur, Sialkot and Rohtak, 207 contained cotton, the total weight of which was $12\frac{1}{2}$ *seers*—$6\frac{3}{4}$ *seers* from near the mouth of the burrows and $5\frac{3}{4}$ *seers* from the bottom of the burrows. No living Pink-Bollworm was found in the material obtained from the bottom of the rat burrows, but 8 living caterpillars were found from the *kapas* collected at the mouth of the burrows at Sialkot and Rohtak during February and March. The rats feed on cotton seed and it is, therefore, most likely that all caterpillars resting in the seed

* See also Richards, 1929—Non-survival of Caterpillars in the soil in the U. P. after April.

get destroyed and that even those few discovered at the opening of the burrows would have been eaten up in due course, At any rate, the number is so exceedingly small that it is negligible as a source of infestation.

Incidentally it may be stated that during various field surveys it was noticed that the seeds of *kapas* on the surface of the soil were frequently eaten up by rats, while those which were below the surface were left untouched. Thus it may be stated that rats play an important part in destroying a large number of Pink-Boll-worms resting in *kapas* left on the ground.

King and Giffard [1924] found that from the bolls collected by rats and taken to their burrows most, if not all, the larvæ had been eaten up.

TABLE XIII.

Presence of Pink-Bollworm in Kapas *collected from rat-holes.*

Locality	Date of Examination (1929)	Number of rat-holes		*Kapas* collected from rat-holes			
				Near mouth of rat-holes		Inside rat-burrows	
		Examined	Containing *Kapas*	Weight of *kapas* in ounces	Number of living Pink-Boll-worm found	Weight of *kapas* in ounces	Number of living Pink-Boll-worms found
Lyallpur .	February .	11	10	21¾	0	11¾	0
Do. .	March .	14	14	61½	0	32	0
Sialkot .	February .	5	5	1	2	0	0
Do. .	March .	95	86	4½	3	3¼	0
Rohtak .	Do. .	100	92	135	3	139	0
Phillaur .	Do. .	..	..	25	0	0	0
Ropar .	Do. .	40	..	8¾	0	0	0
Do.	April .	..	..	7	0	0	0

Besides, the house rats and mice may carry cotton to their burrows. Johnston [1929] states that "Rats were frequently noticed to carry cotton up into the

roof as nest material. Almost invariably the seed in such cotton was found to be eaten. Any living larvæ contained in such seed would undoubtedly be destroyed."

Conclusion.—Thus it may be stated that the hibernating Pink-Bollworms taken in the infested seed by rats or mice are all destroyed.

(5) The Fate of Pink-Bollworms present in Bolls attached to Cotton sticks stored as Fuel.

The Pink-Bollworms in bolls on sticks.—After the final picking a large number of the unopened or imperfectly developed bolls remains on the plants and these bolls often harbour a large population of resting Pink-Bollworms (Table VI). During the uprooting of cotton plants some of these bolls are knocked off, and their share in the incidence of Pink-Bollworm has already been dealt with (see under 2 and 3), but a considerable number is carried away from the fields along with the stricks. The fate of these Bollworms remains to be studied.

The Cotton sticks.—In the Punjab the cotton sticks are mostly used as fuel, but may in small quantities be also used as thatch for roof, for making fences, sticking peas, etc. Even those that are used as fuel remain undisposed of for many months. In order to obtain information regarding the consumption of stored sticks two sets of observations were made. In one case ten heaps of stored sticks were kept under observation and their dimensions measured every month (Table XIV), and in the other case an estimate was made in June of the total quantity of unconsumed sticks in ten villages (Table XV). These investigations show that during January and February there was practically no consumption of cotton sticks, both in the South-Eastern Punjab, where most of the cotton sticks are cut during November and December, and in the Western Punjab including the Colony Areas, where the sticks are cut during January to March (Table III). This is most probably on account of the fact that in winter the freshly cut sticks are still wet and thus unfit for use as fuel.

The use of sticks as fuel begins immediately after the winter, *i.e.*, from the middle of March, and is continued till as late as September. It was, however, observed that by the beginning of July more than three-fourths of the total quantity of sticks originally stored had been burnt. On the sticks that remained only a small number of bolls were present, most of the bolls having got detached had fallen to the bottom of the heap. From Table XVII it will be seen that the number of bolls per 100 sticks was about 50 in January and about 20 in July.

Number and fate of Pink-Bollworms in bolls on sticks.—During 1927 and 1928 observations were started at Rohtak, Sialkot and Lyallpur to find out the number of Pink-Bollworms in bolls on stored sticks. The residual bolls on 100 plants,

TABLE XIV.

Consumption of cotton sticks recorded from ten selected heaps during 1929.

Owner of stick heap and locality	Dimensions of the heaps	Size of stick heap in feet							
		January	February	March	April	May	June	July	August
1. S. Arur Singh, Agric. Asstt., Sialkot.	Length	23	20	18	18	18	17	15½	13½
	Breadth	20⅓	17½	16	15	15	15	14	11
	Depth	5	4½	4	3½	3	2½	2	2
	Volume in cubic feet	2,357	1,575	1,152	945	810	637	434	297
2. R. S. Sohna Mal, Fatehgarh, Dist. Sialkot.	Length	22	22	22	15½	14½	12	12	0
	Breadth	17	17	16½	13	12	9	9	0
	Depth	4¾	4¾	4	3	3	3	2	0
	Volume in cubic feet	1,776	1,776	1,452	605	522	324	216	0
3. S. Sadhu Singh, Chak 213, Dist. Lyallpur.	Length	45	43	38	38	32	30	30	25
	Breadth	6½	6½	4½	4½	4½	4½	4½	4½
	Depth	6	5	4	4	4	4	4	4
	Volume in cubic feet	1,755	1,397	684	684	576	540	540	450
4. S. Thaker Singh, Lyallpur City	Length	46	46	42	35	34	32	29	24
	Breadth	11½	11½	10	10	10	10	10	9
	Depth	6	6	6	5	4	4	4	4
	Volume in cubic feet	3,174	3,174	2,520	1,750	1,360	1,280	1,160	864

5. Baildar, Cotton Research Laboratory, Lyallpur.	Length	28	28	22	19	16½	14	0	0
	Breadth	20	20	15½	15	9	6	0	0
	Depth	5½	5½	5½	5½	3	3	0	0
	Volume in cubic feet	3,080	3,080	1,875	1,567	446	252	0	0
6. L. Mehar Chand, Sunderpur, Dist. Rohtak.	Length	11½	11½	11½	11½	11½	0	0	0
	Breadth	7½	7½	7½	7½	7½	0	0	0
	Depth	9	9	7½	5	3	0	0	0
	Volume in cubic feet	776	776	647	432	259	0	0	0
7. L. Lachman Das, Singpura, Dist. Rohtak.	Length	13½	13½	13½	13½	13½	8	0	0
	Breadth	8	8	8	8	8	4	0	0
	Depth	8½	8½	8½	5½	3½	2	0	0
	Volume in cubic feet	918	918	918	594	378	64	0	0
8. Manjoo Jat, Bohar, Dist. Rohtak.	Length	23¼	23¼	20	19	19	19	19	18
	Breadth	8½	8½	8½	8½	8½	8½	8½	8½
	Depth	..	9	9	9	9	9	7	6
	Volume in cubic feet	1,779	1,779	1,530	1,453	1,453	1,453	1,130	918
9. Jagu Garhi, Dist. Rohtak	Length	16¾	16¾	16¾	16¾	16¾	16¾	14¾	14¾
	Breadth	8½	8½	8½	8½	8½	8½	8½	8½
	Depth	9	9	6	6	5½	5	4	4
	Volume in cubic feet	1,281	1,281	854	854	783	712	501	501
10. Agric. Asstt., Agri. Farm, Rohtak	Length	10	10	10	10	0	0	0	0
	Breadth	8	8	8	8	0	0	0	0
	Depth	7	5	3½	2	0	0	0	0
	Volume in cubic feet	560	400	280	160	0	0	0	0
Total	Volume in cubic feet	17,456	16,156	11,912	9,044	6,587	5,262	3,981	3,030
Percentage of sticks left unconsumed	...	100·0	92·6	68·3	51·8	37·7	30·2	20·3	17·3

TABLE XV.

Cotton sticks used as fuel in Rohtak and Lyallpur districts during 1929.

Name of village	Number of cultivators	Approximate area in acres								Total consumption of sticks	Percentage sticks consumed till June
		Under cotton	Of which sticks were not cut till June	Of which sticks were cut and the dry sticks burnt before June as follows							
				100%	75%	66%	50%	33%	25%		
I. DISTRICT ROHTAK.											
1. Garhi	68	154	0	59	70	0	22½	2½	0	123¾	80·4
2. Dobh	70	31	0	28	0	0	0	0	3	28¾	92·7
3. Singhpura	71	132	0	75½	40	0	11	0	5½	112½	85·2
4. Sunderpura	98	181	3	114	48	0	10	0	6	156½	86·5
5. Manch	30	49½	2½	33½	13½	0	0	0	0	43½	87·9
6. Kanehli	22	42½	0	17	12	13½	0	0	0	35	82·4
Total	359	590	5½	327	183½	13½	43½	2½	14½	500	84·7
II. DISTRICT LYALLPUR.											
1. Chak 279	10	113½	0	6½	0	23	58½	25½	0	59½	52·4
2. Chak 207	8	19¼	0	3¼	0	0	12½	0	3½	10¼	52·9
3. Chak 270	14	95½	0	62½	4½	0	0	0	28½	73	76·4
4. Chak 213	14	154½	2	20	0	0	96½	23	13	79¼	51·1
5. Chak 122	25	208½	7½	12	6½	41½	90¾	28½	2½	100	48·0
Total	71	591¼	9½	104¼	11	64½	258¼	77	47½	322	54·5

which were pulled out in December 1926 and 1927 respectively and stored, were stripped and examined once in a month for living caterpillars. The results of these observations are given in Table VI, columns 5, 10 and 15. It will be seen that from January to April the number of living Pink-Bollworms in bolls on stored sticks was fairly large, and after April there was a gradual fall, till in August all caterpillars had either died or possibly emerged as moths.

Conditions to which Pink-Bollworms in bolls on stored sticks are subjected.— To study the conditions to which the hibernating Pink-Bollworms in bolls on cotton sticks are subjected, detailed observations were made in 1929. Two heaps of cotton sticks were selected, one at Sialkot and the other at Rohtak. At Sialkot a record of temperature of the bolls attached to the upper and lower sticks of the heap was maintained, and at Rohtak a similar record of air temperature was kept (Table XVI). It was seen that the air temperature at the top and lower portion of the stick heap was almost the same, the difference never exceeding 1 to 3°C. In case of bolls, however, the difference was very great, the temperature of the bolls exposed to direct sun-heat was 8 to 10°C. higher than that of the bolls not thus

TABLE XVI.

Temperature of air and bolls in the upper and lower portions of cotton-stick heap.

Dates (1929)		Temperature range (C.) of air in cotton stick heap (Rohtak)		Temperature range (C.) of bolls attached to stored sticks (Sialkot)	
		Upper portion	Lower portion	Upper portion	Lower portion
January	1st to 15th.	20—24	18—23	..	..
	16th to 31st	21—25	18—23	..	..
February	1st to 14th	21—32	19—31	..	..
	15th to 28th	27—34	23—33	22—34	15—24
March	1st to 15th	30—35	29—34	28—36	18—29
	16th to 31st	35—41	34—40	27—42	25—33
April	1st to 15th	38—41	37—39	35—50	29—36
	16th to 30th	40—48	37—43	36—51	30—42

Temperature of air and bolls in the upper and lower portions of cotton-stick heap—contd.

Dates (1929)	Temperature range (C.) of air in cotton stick heap (Rohtak)		Temperature range (C.) of bolls attached to stored sticks (Sialkot)	
	Upper portion	Lower portion	Upper portion	Lower portion
May . . { 1st to 15th .	41—48	40—44	42—53	38—43
{ 16th to 31st .	40—46	37—44	40—52	34—43
June . . { 1st to 15th .	39—45	39—45	39—52	34—40
{ 16th to 30th .	38—45	38—42	32—52	27—42
July . . { 1st to 15th .	35—44	34—42	30—47	25—42
{ 16th to 31st .	34—39	33—38	26—40	25—35
August 1st to 15th . . .	35—38	35—36	..	..

exposed such as those on sticks on the lower side of the heap and bolls lying on the ground under the shade of the stick heap. It was further noticed that while the temperature of the bolls on the lower sticks of the heap and those lying on the ground at the bottom of such heaps was never more than 40°C., it was as much as 50°C. (temperature fatal to Pink-Bollworm) or even more in the case of bolls attached to the upper portion of the stick heap and exposed to the sun. Thus the temperature to which the caterpillars resting in stacked sticks were exposed depends on their position in the heap.

To determine the effect of temperature on the caterpillars in the bolls in the upper portion of the stick heap it was arranged to examine fortnightly (from January to August 1929) bolls sticking to the upper and lower portions of the stick heaps (Table XVII). These observations showed that up to the middle of April there was little difference in the percentage mortality of the Pink-Bollworm resting in the bolls on the top of stick-heap and the bottom of the heap, but afterwards when the season had become hot, the caterpillars in the top bolls began to die at a much rapid rate than those in the bottom ones. And towards the end of May while there was no living Pink-Bollworm in the top bolls, it was possible to find a fair number in the bottom bolls. Observations made during June to August showed that while the number of living Pink-Bollworms was considerably reduced, some living caterpillars were always found in the bottom bolls. The number estimated from 1,000 such bolls examined at Rohtak was 191 in June, 68 in July and 8 in August.

This amply shows that a large number of caterpillars resting in bolls attached to the sticks lying right under the heap and in those that had broken off and shifted down to the ground, is likely to survive up to July and August, when the new cotton crop is fairly well advanced.

TABLE XVII.

Presence of Pink-Bollworm in bolls sticking to the upper and lower parts of cotton-stick heap.

Locality	Dates (1929)	Upper part of stick-heap						Lower part of stick-heap.					
		Number of sticks examined	Number of bolls found	Number of Pink-Bollworms found			Estimated number of living Pink-Bollworms found per 1,000 bolls	Number of sticks examined	Number of bolls found	Number of Pink-Bollworms found			Estimated number of living Pink-Bollworms found per 1,000 bolls
				Living	Dead	Percentage mortality				Living	Dead	Percentage mortality	
Rohtak	January 1-15	400	131	36	11	23·4	275	400	131	46	10	17·0	351
	January 16-31	600	220	89	3	3·3	405	600	231	94	1	1·1	407
	February 1-14	600	208	113	7	5·8	543	600	198	124	3	2·4	626
	February 15-28	600	165	69	16	18·8	418	600	189	92	27	22·7	487
	March 1-15	600	116	67	23	25·5	578	600	116	67	28	29·4	578
	March 16-31	600	129	71	46	39·3	550	600	139	90	39	30·2	648
	April 1-15	1,000	232	78	106	57·6	336	1,000	250	99	112	53·1	396
	April 16-30	500	109	11	59	84·3	101	500	143	32	64	66·6	224
	May 1-15	800	170	5	92	94·8	29	800	172	18	69	79·3	105
	May 16-31	400	90	4	29	87·9	44	400	99	14	34	70·8	141
	June 1-15	400	54	0	18	100·0	0	400	68	13	21	61·8	191
	June 16-30	400	103	1	31	96·9	10	400	127	16	32	66·6	126
	July 1-15	300	106	2	36	94·7	19	300	118	8	33	80·5	68
	July 16-31	300	107	0	19	100·0	0	300	130	7	27	79·4	54
	August 1-15	..	..	..	..	..	..	400	134	1	9	90·0	8
	August 16-31	..	..	..	..	..	..	400	85	0	2	100·0	0
Sialkot	February 1-14	200	120	16	1	5·9	133	..	..	..	..	..	..
	February 15-28	200	332	15	8	34·8	45	200	236	22	3	12·0	93
	March 1-15	100	105	8	2	20·0	76	100	165	18	1	5·3	109
	March 16-31	100	160	11	11	50·0	69	100	92	4	9	69·2	43
	April 1-15	100	140	8	8	50·0	57	100	77	7	8	53·3	91
	April 16-30	100	110	8	10	55·5	73	100	80	7	10	58·8	88
	May 1-15	100	69	1	11	91·7	14	100	57	1	5	83·3	18
	May 16-31	200	183	0	31	100·0	0	200	158	5	30	85·7	19
	June 1-15	100	64	1	12	92·3	0	100	119	2	13	86·7	17
	June 16-30	200	129	0	22	100·0	0	200	82	1	28	86·6	12
	July 1-15	100	37	0	5	100·0	0	200	46	0	14	100·0	0
	July 16-31	100	59	0	10	100·0	0	200	60	0	12	100·0	0

In another set of experiments, cotton sticks pulled out in December 1928 were placed in wire gauge cages (6×6×6 feet) in January, March and May 1929, at Rohtak and Sialkot and the emergence of moths recorded (Table XVIII). The sticks stored in January gave 58 moths at Sialkot and 16 at Rohtak, those stored in March gave 17 moths at Sialkot and 14 at Rohtak, while those stored in May gave 15 moths at Sialkot and 4 at Rohtak. These moths were obtained between the first week of April and the second week of July. These figures of emergence, though few in number, are of great interest showing that the moths can emerge, from heaps of cotton sticks as late as middle of July, when they are positively dangerous to the cotton crop.

Conclusion.—In short, the facts collected go to show that the living Pink-Bollworms may be found in bolls on stored sticks as late as July, and that the moths may emerge at a time when the next cotton crop is beginning to produce bolls, and that such heaps of sticks are a source of infestation to be guarded against.

It is very likely that most of the moths emerging from such heaps reach the cotton fields, as the sticks are stored in fully exposed places often quite close to such fields.

The importance of this source of infestation is fully recognized in Egypt and great stress is laid on the removal and destruction of dead bolls attached to cotton sticks. Ballou [1920], after giving a careful consideration to the opinions invited by him from inspectors working in different provinces of Egypt, came to the conclusion that 'the cotton plants ought to be cut and pulled immediately after the crop is picked and removed from the field to a central cleaning place where the removal of the bolls could be proceeded with leisurely.' He further says that 'the

TABLE XVIII.

Emergence of Platyedra *moths from cotton sticks kept in wire gauze cages during 1929.*

Dates (1929)		Number of *Platyedra* moths from cotton sticks					
		Stored on 1st January		Stored on 1st March		Stored on 1st May	
		Sialkot	Rohtak	Sialkot	Rohtak	Sialkot	Rohtak
January	1st to 15th	0	0	..	..	..	..
	16th to 31st	0	0	..	..	..	..
February	1st to 14th	0	0	..	..	..	..
	15th to 28th	0	0	..	..	..	..

Emergence of Platyedra *moths from cotton sticks kept in wire gauze cages during 1929*—contd.

Dates (1929)		Number of *platyedra* moths from cotton sticks					
		Stored on 1st January		Stored on 1st March		Stored on 1st May	
		Sialkot	Rohtak	Sialkot	Rohtak	Sialkot	Rohtak
March	1st to 15th	0	0	0	0	..	..
	16th to 31st	0	0	0	0	..	..
April	1st to 15th	6	12	0	13	..	..
	16th to 30th	5	0	1	0	..	..
May	1st to 15th	0	1	0	0	1	0
	16th to 31st	15	0	5	0	5	0
June	1st to 15th	23	0	5	0	5	0
	16th to 30th	3	0	2	0	2	0
July	1st to 15th	6	3	4	1	2	4
	16th to 31st	0	0	0	0	0	0
August	1st to 15th	0	0	0	0	0	0
	16th to 31st	0	0	0	0	0	0
Total		58	16	17	14	15	4

date at which the cultivators should be made to remove the cotton sticks from the fields should be fixed as early as possible.....No sticks or bolls should be allowed in the villages before a fixed date, at which time all sticks must be cleaned and a permit given to the whole village to remove the clean sticks. All bolls and trash in the central cleaning place should either be burnt at once or otherwise satisfactorily disposed of.'

Cleaning up the cotton fields, especially the destruction of bolls left on sticks, is also recommended by the Ministry of Agriculture, Egypt [1914], Ramirez [1918], Loftin [1919], Loftin, Mackinney and Hanson [1921], Townshend [1920], and Stock [1926]. As an aid to this Loftin points out the value of pasturing sheep and other animals in the cotton fields. Our observations go to show that if cotton sticks are left standing in the fields there is less danger of attack than in the case of sticks cut and stacked with bolls on them.

(6) The Fate of Pink-Bollworms in Low-grade Cotton and heaps of *patti* (refuse).

The Pink-Bollworm resting in loosely united double seeds, lint, etc., get separated during the cleaning operation, and with other rubbish are thrown on the heap of *patti* (dried leaves, sticks, etc.), and inferior quality of seed-cotton kept either in the open yards of the ginning factories or under open sheds. In certain factories the *patti* is used as fuel, but in most of them it is allowed to accumulate year after year and then sold as manure. It is sometimes also mixed with mud and used for plastering the roofs of houses.

Amount of patti.—During summer 1928 an attempt was made to estimate the total weight of *patti* stocked in some selected factories of the province, and as will be seen from Table XIX, the stock varied from three to, as much as, two hundred maunds in one factory.

Table XIX.

Estimated weight of patti *accumulated in different ginning factories in the Punjab, during 1928.*

Date of visit (1928)	Name of ginning factory and location	Approximate weight in mds. of *patti* stored in the factory	Number of living Pink-Bollworms found in two pounds of *patti*
April 15th	Ujjal Singh, Davinder Singh, Sargodha	200	3
	Ganesh Cotton Factory, Sargodha	40	0
	Illam Din, Mohd. Din, Sargodha	50	2
	Kartar Singh, Partap Singh, Sargodha	70	6
	Nihal Singh, Sargodha	30	1
	Japan Cotton Trading Company, Sargodha	5	0

Estimated weight of patti *accumulated in different ginning factories in the Punjab, during 1928*—contd.

Date of visit (1928)	Name of ginning factory and location	Approximate weight in mds. of *patti* stored in the factory	Number of livin Pink-Boll wormg found in two pounds of *patti*
April 21st	Banka Mal, Narinjan Das, Moga	25	12
	Aggrawal Cotton Mills, Moga	3	10
,, 25th	Mohan Lal Srikishen, Rohtak	60	12
	Gopal Mal, Shankar Das, Rohtak	13	8
,, 29th	Dhanpat Mal Bhagwan Das, Montgomery	50	0
	Japan Cotton Trading Company, Montgomery.	150	0
	R. B. Narain Singh & Sons, Montgomery	60	0
,, 30th	Bahadur Mal, Shankar Dass, Pattoki (Lahore).	25	4
	Bankamal, Narinjan Dass, Pattoki (Lahore).	20	1
	Hazarimal, Biharimal, Pattoki (Lahore)	35	4
	Ghulam Farid, Fazal Din, Pattoki (Lahore)	50	6
	Japan Cotton Trading Company, Pattoki (Lahore).	10	3
June, 1st	Dhanpatmal Bhagwan Dass, Lyallpur	8	0
	Maula Bux, Lyallpur	30	0
	Kirpa Ram, Brij Lal, Lyallpur	10	0
	Tata & Co., Lyallpur	6	0
,, 5th	Nathushah Gopal Dass, Lyallpur	8	0
	Dhanpatmal Dewan Chand, Lyallpur	30	0
	Sh. Mohd. Alla Bux, Lyallpur	30	0
	Mathra Dass, Lyallpur	6	0

Number of hibernating Pink-Bollworms in patti.—As regards the caterpillars resting in *patti*, preliminary observations were made during 1927 and 1928 at Rohtak, Sialkot and Lyallpur (Table XX). At each locality about two lbs. of *patti* was procured once a month from January to August, and the material examined for living Pink-Bollworms. These observations show that this material may contain as many as 246 living Pink-Bollworms per lb. of *patti* and the living caterpillars may be recovered as late as July, and may thus be a source of Pink-Bollworm moths.

Emergence of moths from patti.—To obtain further details, a heap of *patti*, weighing about fifty maunds, was kept in a store at Rohtak, and observations on the emergence of *Platyedra* moths were made for a period of eight months, *i.e.*, from January to August 1927. The results of this are summarised below :—

Month	Temperature (C.) of *patti* heap recorded at 4 P. M.	Number of moths emerged
January	15—18	0
February	17—21	0
March	19—26	19
April	25—35	29
May	33—38	47
June	36—37	72
July	31—37	148
August	30—34	6

These observations show that the highest emergence occurred in July when the cotton crop was producing flowers and bolls.

Conclusion.—It will be observed that the quantity of this gin-trash is sometimes quite large, and the population of the resting Pink-Bollworms in it fairly great. It is possible that this source, although not one of the principal causes, is an important subsidiary factor in Pink-Bollworm incidence. It is, therefore, desirable that the pest present in the *patti*, etc., in the ginning factories be dealt with. Nothing better and safer than the use of this dangerous material as fuel can be recommended. The factory owners are not usually directly interested in the safety of the crop and may not realise that it is to their advantage if Pink-Bollworm disappears.

The importance of low-grade cotton and other gin-trash as a source of infestation has also been recognised in Texas (U. S. A.). Coad [1929], while carrying out somewhat similar observations, has greatly emphasised the importance of the gin and oil mills as points for concentration of infestation and the extreme necessity of prompt disposal of all gin-trash.

TABLE XX.

Pink-Bollworms found in patti.

Month (Year 1927)	Rohtak			Sialkot			Lyallpur		
	Weight in ounces of *patti* examined	Number of living Pink-Boll worms found	Number of Pink-Boll-worms per lb. of *patti*	Weight in ounces of *patti* examined	Number of living Pink-Bollworms found	Number of Pink-Boll worms per lb. of *patti*	Weight in ounces of *patti* examined	Number of living Pink-Bollworms found	Number of Pink-Boll-worms per lb. of *patti*
January .	14½	113	124	31½	412	209	60	24	6
February .	39½	14	6	74¾	587	126	..	..	..
March .	41½	10	4	83¾	444	85	66½	246	59
April . .	33¾	6	3	83	163	31	66½	142	34
May . .	43½	12	4	78¾	32	7	66½*	0*	0*
June . .	44	2	1	78¾	17	3	232½*	0*	0*
July . .	35¼	4	2	83	3	1	32*	0*	0*
August .	39½	0	0	82¼	0	0	25¾*	0*	0*

Figures marked (*) are for 1928.

(7) THE FATE OF PINK-BOLLWORMS IN *KAPAS* AND COTTON-SEED KEPT IN STORES.

It has already been shown that a very large proportion of Pink-Bollworms is removed from the fields in picked cotton. A part of this cotton remains in the villages for local use, but most of it is brought to the towns for sale.

The quantity of kapas and cotton-seed kept in villages.—In 1928 observations were made to get an estimate of the quantity of *kapas* and cotton-seed kept in villages. The investigation was carried out in two districts, namely Rohtak (in South-Eastern Punjab), where *desi* varieties are grown, and Lyallpur (in Colony Areas) where both *desi* and American cottons are planted. In each district eight villages were selected, and from each village the following data collected, from all the cotton growers (excepting a few) :—

I. For *kapas*.

(1) Area sown under cotton.

(2) Variety, *desi* or American.

(3) Outturn of *kapas*.

(4) *Kapas* sold in market, date of selling.
(5) *Kapas* kept for household use; date of ginning.
(6) *Kapas* left unconsumed.

II. For cotton-seed.
(1) Quantity of seed from *kapas* locally ginned.
(2) Quantity brought from markets.
(3) Quantity locally consumed, and balance in stock.

The above information was collected on three different dates:—3rd week of January, 1st week of March, and 3rd week of June. The results of this investigation have been tabulated in Tables XXI and XXII.

This enquiry has brought to light the interesting fact that both in the Rohtak District, South-Eastern Punjab, where *desi* cotton is cultivated, and in Lyallpur

TABLE XXI.

Cotton-seed stored in sixteen villages of Rohtak and Lyallpur Districts, during the period January to June 1928.

District	Date of visit	Name of village	Weight of cotton-seeds									
			In stock		Locally ginned		Brought from market and other sources		Locally consumed		Balance	
			Mds.	Srs.	Mds.	Srs.	Mds.	Srs.	Mds.	Srs.	Mds.	Srs.
Rohtak	January 3rd week.	Pie	0	0	25	20	36	10	23	24	38	6
		Bhainswan	0	0	41	33	61	20	39	20	63	33
		Pahrawar	0	0	38	16	43	25	36	19	45	22
		Thanakhurd	0	0	18	10	24	0	18	10	24	0
		Bhalaut	0	0	149	26	198	0	142	4	205	22
		Ranakheri	0	0	3	36	6	0	3	36	6	0
		Silana	0	0	110	23	60	21	92	26	78	18
		Lahli	0	0	38	38	24	20	33	2	30	16
		Total	0	0	427	2	454	16	389	21	491	37

Cotton-seed stored in sixteen villages of Rohtak and Lyallpur Districts, during the period January to June 1928—contd.

District	Date of visit	Name of village	Weight of cotton-seeds				
			In stock	Locally ginned	Brought from market and other sources	Locally consumed	Balance
			Mds. Srs.	Mds. Srs.	Mds. Srs.	Mds. Srs.	Mds. Srs.
Rohtak .	March 1st week.	Pie . .	38 6	12 26	9 30	38 18	22 4
		Bhainswan .	63 33	17 11	10 25	65 18	26 11
		Pahrawar .	45 22	20 6	15 4	46 18	34 14
		Thanakhurd .	24 0	9 7	13 0	24 26	21 21
		Bhalaut .	205 22	67 24	12 10	171 14	114 2
		Ranakheri .	6 0	0 39	2 0	4 14	4 25
		Silana . .	78 18	38 25	22 0	88 22	50 21
		Lahli . .	30 16	16 8	3 16	31 2	18 38
		Total .	491 37	182 26	88 5	470 12	292 16
	April 3rd week.	Pie . .	22 4	0 0	21 36	30 34	13 6
		Bhainswan .	26 11	0 0	39 26	43 25	22 12
		Pahrawar .	34 14	0 0	16 13	29 26	21 1
		Thanakhurd .	21 21	0 0	7 25	16 6	13 0
		Bhalaut .	114 2	0 0	61 3	97 5	78 0
		Ranakheri .	4 25	0 0	2 4	3 4	3 25
		Silana . .	50 21	0 0	65 26	62 31	53 16
		Lahli . .	18 38	0 0	17 18	22 28	13 28
		Total .	292 16	0 0	231 31	305 39	218 8

Cotton-seed stored in sixteen villages of Rohtak and Lyallpur Districts, during the period January to June 1928—contd.

District	Date of visit	Name of village	Weight of cotton-seeds							
			In stock		Locally ginned		Brought from market and other sources		Locally consumed		Balance	
			Mds.	Srs.	Mds.	Srs.	Mds.	Srs.	Mds.	Srs.	Mds.	Srs.
Rohtak	June 3rd week.	Pie	13	6	0	0	3	20	13	6	3	20
		Bhainswan	22	12	0	0	6	0	23	22	4	30
		Pahrawar	21	1	0	0	0	16	21	1	0	16
		Thanakhurd	13	0	0	0	28	20	27	33	13	27
		Bhalaut	78	0	0	0	88	35	90	39	75	36
		Ranakheri	3	25	0	0	5	0	5	5	3	20
		Silana	53	16	0	0	50	15	63	18	40	13
		Lahli	13	28	2	0	8	5	19	13	4	20
		Total	218	8	2	0	190	31	264	17	146	22
Lyallpur	January 3rd week.	Chak 263	0	0	13	13	35	20	23	0	25	33
		Chak 67	0	0	19	32	0	0	0	0	19	32
		Chak 43	0	0	8	16	49	20	25	20	32	16
		Chak 282	0	0	0	0	55	0	55	0	0	0
		Chak 110	0	0	0	33	0	0	0	0	0	33
		Chak 213	0	0	12	35	34	0	17	0	29	35
		Chak 197	0	0	5	17	4	0	2	0	7	17
		Chak 2	0	0	20	35	12	0	7	0	25	35
		Total	0	0	81	21	190	0	129	20	142	1

Cotton-seed stored in sixteen villages of Rohtak and Lyallpur Districts, during the period January to June 1928—concld.

District	Date of visit	Name of village	Weight of cotton-seeds.				
			In stock	Locally ginned	Brought from market and other sources	Locally consumed	Balance.
			Mds. Srs.	Mds. Srs.	Mds. Srs.	Mds. Srs.	Mds. Srs.
Lyallpur .	March 3rd week.	Chak 263 .	25 33	8 38	0 0	3 0	31 31
		Chak 67 .	19 32	1 20	224 20	115 5	130 27
		Chak 43 .	32 16	4 18	6 20	10 30	32 24
		Chak 282 .	0 0	0 0	0 0	0 0	0 0
		Chak 110 .	0 33	0 30	6 0	5 0	2 23
		Chak 213 .	29 35	0 0	0 0	6 0	23 35
		Chak 197 .	7 17	10 18	83 0	43 35	57 0
		Chak 2 .	25 35	0 0	17 0	6 30	36 5
		Total .	142 1	26 4	337 0	190 20	314 25
	June 3rd week.	Chak 263 .	31 31	0 4	13 0	35 15	9 20
		Chak 67 .	130 27	0 0	9 0	60 5	79 22
		Chak 43 .	32 24	0 0	6 0	2 0	36 24
		Chak 282 .	0 0	0 0	160 0	100 0	60 0
		Chak 110 .	2 23	0 0	80 0	80 0	2 23
		Chak 213 .	23 35	2 29	6 20	5 32	27 12
		Chak 197 .	57 0	0 7	0 0	4 0	53 7
		Chak 2 .	36 5	0 0	0 0	0 0	36 5
		Total .	314 25	3 0	274 20	28 12	304 33

TABLE XXII.

Estimate produce and sale of kapas *from sixteen villages of Rohtak and Lyallpur Districts during* kharif *1927-28.*

District	Village	Number of cultivators	Area under cotton in acres	Yield of *kapas*		*Kapas* sold in market		*Kapas* consumed locally		*Kapas* unconsumed till June 1928	
				Desi	American	*Desi*	American	*Desi*	American	*Desi*	American
				Mds.	Mds.	Mds.	Mds.	Mds.	Mds.	Mds.	Mds.
Rohtak	Rana Kheri	6	7½	30	..	22½	..	7½	..	0	..
	Pie	28	27¾	56	..	..	..	56	..	0	..
	Thana Khurd	25	27½	141½	..	99½	..	42	..	0	..
	Bhainswan	40	93	464½	..	374½	..	90	..	0	..
	Pahrawar	45	93⅛	383	..	293	..	90	..	0	..
	Bhalaut	119	333	1,421⅛	..	1,089⅛	..	332	..	0	..
	Silana	90	123¼	606½	..	372	..	234½	..	0	..
	Lahili	34	57⅛	318½	..	234½	..	84	..	0	..
	Total	387	762¾	3,421½	..	2,485½	..	936	..	0	..
Lyallpur	Chak 263	87	314	1,141¼	38½	1,041½	38½	99¾	0	0	0
	Ckak 67	91	244½	848¾	107½	769	107½	79¾	0	0	0
	Chak 43	40	192½	520½	67½	478½	67½	42	0	0	0
	Chak 282	60	185½	101¼	829½	83¼	811½	18	18	0	0
	Chak 110	61	313¼	28½	1,409	12	1,406½	16½	2½	0	0
	Chak 213	24	171¼	833¾	364	796¼	364	37½	0	0	0
	Chak 197	68	325¾	1,148½	121	1,104¼	121	44¼	0	0	0
	Chak 2	35	220½	209	1,045¼	179	993¾	30	51½	0	0
	Total	466	1,967¼	4,831½	3,982¼	4,463¾	3,910¼	367¾	72	0	0

district, where Americans and *desis* are grown, the bulk of the crop—both *desi* and American—is very often immediately sold in the neighbouring market. This *kapas* is then ginned and pressed in the factories. It was observed, however, that the quantity of *kapas* retained in the villages of the Rohtak district was generally far more than that kept in the villages of the Lyallpur district. In the Rohtak district it was about 27 per cent. of the total produce, as against only 5 per cent. of the total in the Lyallpur district. The average quantity of *kapas* kept by each cultivator for his domestic needs was found to be $2\frac{1}{2}$ maunds in the Rohtak district against less than one maund in the Lyallpur district, as shown below :—

District	Number of cultivators under observation	*Kapas* sold in the market	*Kapas* kept for local consumption	Percentage of total produce	*Kapas* kept by each cultivator
		Mds.	Mds.		Mds.
Rohtak.	387	2,485½	936	27·4	2·42
Lyallpur	466	8,374	439	5·4	0·94

During this enquiry it was also found that most of the cotton in villages was ginned before the 3rd week in June. It has been further ascertained that the total production of seed-cotton left unginned after June was very small both in villages and in towns, in fact the quantity was never more than a few handfuls of spoiled cotton. Large quantities of seed, however, remain undisposed of till the next crop. A certain quantity is fed to cattle during winter, but a sufficient quantity is kept for sowing or for use as food for cattle all through the cotton season (Table XXI). Thus in the Punjab it is the cotton seed in which the hibernating caterpillars remain.

Quantity of seed stored.—The results of village enquiry carried out in 1928 (Table XXI) further indicate that there was a regular pouring in of the seed from the market to the villages from January to June. After the rains had set in, *i.e.*, during July or August, fresh quantities of seed were rarely brought in. It was seen that towards the end of June, in certain villages in the Rohtak district, as many as 78 maunds of seed was in stock, containing about twenty-five thousand resting Pink-Bollworms (Table XXI).

The major portion of the seed is stocked in the ginning factories up to April, after which the factory owners generally dispose of their entire stock to *arties* (big merchants), who in their turn often keep their stock as late as August, or sometimes even later if the rates are not suitable. Thus fairly large quantities

of seed remain undisposed of till June, both in villages and in towns, and this stored seed contains a large number of Pink-Bollworms.

In countries, where Pink-Bollworm enters into a long period of hibernation, cotton seed has been found to be the main source of infestation. This fact has been emphasised by practically every one working on Pink-Bollworm. The investigations of Gough [1916], Willcocks [1916], Ballou [1920], Storey [1921] and Williams [1924] in Egypt; Fletcher [1917], Richards [1924, 1927] and Clouston [1928] in India; Huddleston [1925], King [1928] and Johnston [1929] in the Sudan; Ballard [1926], Goode [1926] and Evans [1926] in Australia; Macdonald [1927] in Texas (U. S. A.); and Jacobsen [1927] in California, have shown that the untreated seed is the chief agent in the carrying over of the Pink-Bollworm. The question of hibernating caterpillars in seed store has, therefore, been fully studied.

Methods of storage of seed.—The cotton seed is stored in towns, as well as in villages. In villages the cotton seed is kept by the zemindars, as well as, the village *banias* (petty shopkeepers). The method of seed storage adopted is very crude and unsatisfactory. The seed may be thrown in the corners of dwelling houses or shops, or put in earthen pots which are seldom covered, and even if covered, they are opened frequently. For sale the seed may be exposed in open baskets or bags. In towns, where seed-stores are often very big, the seed is stocked either in the open barracks of the ginning factories or put in gunny bags and stored in special godowns. It was further seen that these stores were either without doors or with such imperfect doors that moths could easily escape.

The Pink-Bollworms in seed kept in stores.—The seed kept in big stores contains a very large number of caterpillars at the beginning of July, when the crop is coming into flowers. The following table shows the presence of Pink-Bollworm in the seed in 1927 and in 1928 taken from godowns in the towns of Rohtak, Sialkot and Ferozepur :—

Month	Number of living Pink-Bollworms found in one *seer* (2 lbs.) cotton seed					
	Rohtak		Sialkot		Ferozepur	
	1927	1928	1927	1928	1927	1928
January	66	62	49	66	27	78
February	51	54	30	70	36	78
March	—	60	31	46	20	56
April	22	48	20	32	14	32
May	25	51	20	19	17	12
June	20	40	13	13	8	9
July	3	16	6	5	1	3
August	1	1	1	1	1	1
September	0	0	1	0	1	0

Emergence of moths.—This brings us to the consideration of the emergence of moths from the resting caterpillars in seed-stores. During 1927-29 certain experiments were designed to find out the emergence of moths from caterpillars resting in big stores of the town markets and small village-stores. Work on these lines was started at four localities—Rohtak, Sialkot, Ferozepore and Lyallpur.

Big stores.—At each locality fifty maunds of cotton seed locally procured was stored in specially screened stores in January 1927 and 1928 respectively. For each store daily records of temperature and humidity and the emergence of *Platyedra* moths were maintained. The moths were captured in a light trap (from 7 P. M. to 7 A. M.), those not trapped were collected while sitting on the walls of the store.

The collection was found to be fairly complete and it is believed that the number accounted for in Table XXIII was the number actually able to come out of the seed heap and that very few moths had escaped observation.

In all 5,311 moths were caught from the big stores of which 2,676 were females and 2,635 males ; as shown below :—

Month	Number of moths examined			
	Males	Females	Total	Percentage Females
January	42	46	88	52·3
February	120	122	242	50·5
March	146	157	303	51·8
April	299	314	613	51·2
May	432	457	889	51·4
June	452	497	949	52·3
July	732	655	1,387	47·2
August	346	339	685	49.5
September	66	89	155	57·4
Total	2,635	2,676	5,311	50·4

TABLE XXIII.

Emergence of Platyedra moths from cotton seed stores during 1927 and 1928.

Particulars	Number of moths emerged. 1 / Temperature (C.)—average. 2 / Range. 3	Estimated number of Pink-Bollworms under observation	January	February	March	April	May	June	July	August	September	Total	Percentage Pink-Bollworms that reached moth stage	Moths that emerged before 30th June — Number	Moths that emerged before 30th June — Percentage	Moths that emerged after 30th June — Number	Moths that emerged after 30th June — Percentage
I. Fifty mds. cotton seed stored in January 1927 at Rohtak.	1	1,32,000	0	0	36	16	94	110	233	104	11	604	0·5	256	42·4	348	57·6
	2	..	15	18	21	27	32	34	35	32	35	..	..	..	..	..	..
	3	..	14-16	17-20	18-26	26-31	31-36	33-36	34-36	32-34	34-36	..	..	..	..	..	..
II. Fifty mds. cotton seed stored in January 1928 at Rohtak.	1	1,25,000	0	5	42	26	13	169	737	380	2	1,374	1·1	255	18·5	1,119	81·4
	2	..	17	20·5	24	28	34	37	37	35	32	..	..	..	..	..	..
	3	..	16-19	18-22	23-26	26-30	30-38	36-38	34-38	34-37	31-35	..	..	..	..	..	..
III. Fifty mds. cotton seed stored in January 1927 at Sialkot.	1	99,000	0	0	26	28	307	458	250	156	138	1,363	1·4	819	60·1	544	39·9
	2	..	15	16	21	31	35	40	40	38	36	..	..	..	..	..	..
	3	..	14-17	15-18	17-26½	27-34	32-39	39-41	39-42	37-39	34-39	..	..	..	..	..	..
IV. Forty mds. cotton seed stored in January 1928 at Sialkot.	1	1,06,000	0	0	118	356	269	63	76	21	0	903	0·9	806	89·2	97	10·7
	2	..	17	18	25	36	40	41	41	38	37	..	..	..	..	..	..
	3	..	16-19	16-21	22-29	29-40	39-41	41-42	40-42	37-39	34-38	..	..	..	..	..	..
V. Fifty mds. cotton seed stored in January 1927 at Ferozepore.	1	73,000	86	232	35	105	103	44	51	15	4	675	0·9	605	89·6	70	10·4
	2	..	22	23	27	36	41	43	42	42	41	..	..	..	..	..	..
	3	..	20-24	22-24	25-32	31-40	40-42	42-43	42-43	41-42	40-42	..	..	..	..	..	..

VI. Fifty mds. cotton seed stored in January 1927 at Lyallpur.	1	32,000	2	5	44	53	72	104	40	9	..	329	1·0	280	85·1	49	14·9
	2	..	18	20	24	30	34	36	37	36	..	..	..	..	..	..	..
	3	..	17-18	18-21	20-27	28-32	32-36	35-39	35-39	35-37	..	..	..	..	..	..	..
VII. Fifty mds. cotton seed stored in January, 1928 at Lyallpur.	1	3,000	0	0	2	29	31	1	0	0	..	63	2·0	63	100·0	0	0
	2	..	16	18	22	29	37	39	40	37	..	..	..	..	..	..	..
	3	..	14-17	13-22	20-24	23-32	34-41	35-41	38-42	34-40	..	..	..	..	..	..	..
Total Big stores	..	5,70,000	38	242	303	613	889	949	387	685	155	5,311	0·9	3,084	58·1	227	41·9
VIII. One md. cotton seed stored in two wire-gauze cages in January 1928 at Rohtak.	1	2,500	0	0	4	0	0	21	172	38	3	238	9·5	25	10·5	213	89·5
IX. One md. cotton seed stored in two wire-gauze cages in January 1928 at Sialkot.	1	2,600	0	0	0	0	0	67	104	0	0	171	6·6	67	39·2	104	60·8
X. One md. cotton seed stored in two wire-gauze cages in January 1928 at Lyallpur	1	400	0	0	0	0	0	15	7	7	0	29	7·2	15	51·7	14	48·3
Total Small stores	..	5,500	0	0	4	0	0	103	283	45	3	438	8·0	107	24·4	331	75·6

These records incidentally indicate that male and female moths were present in almost equal numbers during different months of the year.

Some of the females caught in the light traps lived for a time and laid eggs which showed normal hatching, indicating thereby that the fertilized females were also attracted to light or were fertilized in the light trap.

As has already been mentioned the capture of the moths by the light trap was quite complete, as in most cases it was difficult to find a moth in the store after the light was put out. This belief was further supported by the results of the following experiment conducted in 1925. Five maunds of cotton seeds, badly infested by Pink-Bollworm, was procured and placed in a special breeding cage built with certain modifications after the design of Willcocks [1916]. In front of the glass door was fitted a 32 candle power electric lamp, which was lighted every evening and put out in the morning. The moths being attracted to light, passed through the narrow openings in the glass louvres towards the glass door and were thus trapped. Every day the moths captured were taken out and their number recorded (Table XXIV). During July to September, as many as 982 moths were captured ; the maximum number caught in one night was as high as 70. At the close of the experiment the seed in the cage was examined and it was found that there were only 8 dead moths and those too at the bottom of the glass louvres. This clearly shows that almost all the moths emerging from the seed were attracted to light*. The moths found at the bottom of the glass louvres were probably those that had died in their attempt to pass through the openings.

TABLE XXIV.

Emergence of long-cycle moths from five maunds of badly infested cotton-seed stored in a large breeding cage at Lyallpur during 1925.

Date	Number of moths emerged			Remarks
	July	August	September	
1	...	8*	3	
2	...	17*	5	
3	...	5	4	
4	30	5	9	
5	32	9	4	
6	48	16	13	
7	2	5	4	
8	3	6	3	
9	18	6	5	
10	33	18	2	

*An account of the positive phototropism of *P. gossypiella*, Saund., is under preparation.

Emergence of long-cycle moths from five maunds of badly infested cotton-seed stored in a large breeding cage at Lyallpur during 1925—contd.

Date	Number of moths emerged			Remarks
	July	August	September	
11	5*	17	9	
12	22	25	2	
13	31	8*	4	
14	24	18*	2	
15	70	19	0	Figures marked (*) are of moths emerged on rainy days.
16	34	11	0	
17	49	12	1	
18	14	10	0	
19	34	17	0	
20	9	11	0	
21	11*	5	1	
22	7	9	0	
23	11	5	0	
24	30	2	0*	
25	21	2	0	
26	10	2	0	
27	12*	2	0	
28	5*	7	0	
29	5*	5	0	
30	19*	2	0	
31	39*	1	0	
Total	628	285	71	
GRAND TOTAL		984		

Temperature and Emergence of moths.—It has now been definitely recognised that long-cycle caterpillars are produced as the result of low temperature and in tracts with an equitable and sufficiently high temperature there is no hibernation, as for instance in Madras [Ballard, 1921] and the coastal region of Kenya colony [Kirkpatrik, 1927]. It has been observed that when the temperature of the stored seed remained favourable, the moths continued to emerge throughout the year and there was no period of complete quiescence (Table XXIII). At a temperature below 20°C. (68°F.) there was no emergence as will be evident from a study of Table XXIII. As the temperature of the stored seed rose from 20°C. to 35-37°C. more and more of the resting caterpillars pupated and emerged as moths; a temperature of 35-37°C. appeared to be the optimum and it will be seen that, during the period that this temperature prevailed, the emergence of moths was often at its highest. From 37°C. upward the number of moths emerging fell and the death occurred after short exposure. Finally at 65°C. the death was almost instantaneous.

Thus if the temperature of a particular seed heap remained below 20°C. during winter, then most of the caterpillars behaved as resting larvæ. On the other hand, when the temperature went above 20°C. during winter (January and February) then most of the caterpillars, which would have taken to hibernation, pupated and emerged as moths. This fact was clearly evident from the observations made on the seed stored at Ferozepore in 1927, as shown below :—

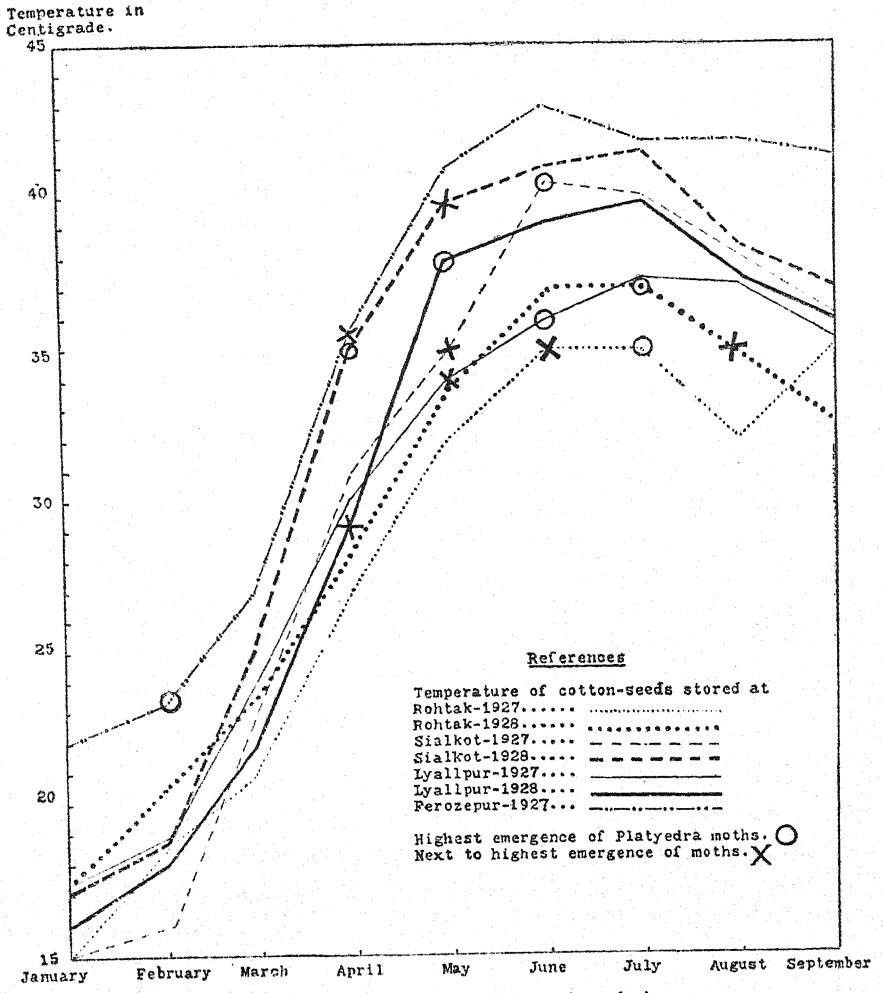
Locality where seed was stored	Number of days from 15th January to 15th February with temperature of stored seed above 20°C.	Number of short (slow) cycle moths (January to February)	Number of long cycle moths (March to September)	Percentage of long cycle moths
Ferozepore, 1927* . . .	32	318	357	52·9
Lyallpur, 1927	3	7	322	57·9
Rohtak, 1928	2	5	1,359	99·6
Lyallpur, 1928	0	0	63	100·0
Rohtak, 1927	0	0	604	100·0
Sialkot, 1927	0	0	1,362	100·0
Sialkot, 1928	0	0	1,071	100·0

Briefly stating, it may be said that at temperature below 20°C. complete dormancy occurred, but as the temperature rose, the insects became more and more active until the optimum was reached at 35-37°C., beyond this the temperature was unfavourable. (The question is being studied further.)

Another interesting fact that has been discovered is that at places like Rohtak (in South-Eastern Punjab) and Sialkot (in Eastern Punjab), where Pink-Bollworm is a serious pest of cotton, the temperature of stored seed during January and February does not ordinarily go higher than 20°C., hence the emergence of moths does not start earlier than March. On the other hand, at places like Lyallpur (Colony Areas), where the Pink-Bollworm is a minor pest, the temperature of the stored seed in certain years goes higher than 20°C. even during January and February and this results in an earlier start of emergence than is the case at Rohtak and Sialkot (Table XXIII).

*Seed was stored in a godown which was about 2 feet below ground level and quite close to the boiler of a factory. In this store it was possible to maintain high temperature even in winter.

As regards the most favourable temperature, *i.e.*, 35-37°C. it was noticed that, at Rohtak during 1927 and 1928 this temperature was reached in July and the maximum emergence was noticed during this very month. At Sialkot during 1927 the most favourable temperature prevailed partly in May and partly in June, and this resulted in high emergence during these months. During 1928, at the same locality, this temperature was obtained in April and this was the month in which the highest emergence for the year was recorded. At Lyallpur during 1928 the most favourable temperature reached in May and in 1927 it prevailed in June, giving the highest emergence in these months, (Fig. 1).



Emergence of Platyedra moths from different seed-stores.

Fig. 1.

This was the condition prevailing in stores at different places in the Punjab, but in certain hot stores the emergence of resting larvæ could be made to start as early as January and February. As stated above in 1927, a specially hot godown was selected at Ferozepore, a place situated on the boundary of South-eastern and Western Punjab, and in this store the temperature remained as high as 20-24°C. even during the winter months (Table XXIII). In this store the maximum emergence of moths took place during winter or early spring. It was further noticed that notwithstanding the fact that atmospheric temperature of Ferozepore (being quite close to the river Bias) is even lower than that of Rohtak, as shown below, it was possible to obtain in a store at Ferozepore the highest emergence as early as February. From this it can be justly concluded that it is the temperature of a particular seed heap that is the chief determining factor in the emergence of moths.

Particulars	Temperature (C.) in shade in 1927			
	Rohtak		Ferozepore	
	January	February	January	February
Highest maximum	27·0	25·0	18·0	20·0
Average maximum	21·9	21·4	16·2	17·5
Average minimum	8·6	19·4	6·5	10·0
Lowest minimum.	4·0	9·8	5·0	9·8

The figures of emergence obtained from these seed stores showed that the number of moths emerging in January and February was very small. During March also very few moths emerged, but from April onward the rate gradually increased till in July the climax was reached, after which the emergence again fell.

Small seed-stores.—Observations were conducted to study the emergence of long-cycle moth from small quantities of seed. One maund of local cotton seed

was stored in January 1928 and 1929 at each of three stations Rohtak, Sialkot and Lyallpur. It was observed that up till May the emergence of moth was very rare in all the three places. At Rohtak and Sialkot it was moderate in June and was highest during July, dropping down again in August. At Lyallpur it was highest during June and continued during July and August. Thus the figures obtained from small heaps agreed with those of the stores in large quantities, with the difference that the percentage of success in completing life-histories is higher in case of small heaps than in cases of large stores.

Having arrived at the conclusion that infested cotton seed remaining in stores until June or July is a source of danger to the new year's crop, the question of the relative importance of big stores in cities and petty stores in villages must be considered. Our experiments with large and small bulks of seed stored at different stations indicate a remarkable difference between the two in so far as the success of emergence of moths is concerned. It was observed that the proportion of emergence in big heaps was not so high as that in petty stores. In stores of fifty maunds of seed the percentage of resting caterpillars reaching the moth stage varied from 0·5 to 2·0, while it was 6·6 to 9·5 in small store of half a maund seed as calculated in Table XXIII. Thus the extent of infection per unit volume of seed does not seem to be so great for big stores as that from small quantities of seed in the possession of petty shopkeepers and zemindars in villages. The reason seemed to be two fold :—

Firstly, the seed in the markets is often placed in large heaps and it seems probable that moths formed from caterpillars resting in seed lying in the lower part of the heaps are not always successful in coming to the surface. This finds support from the results of an experiment, conducted to test the power of Pink-Bollworm moths to come out of a seed heap.

Five glass tubes of two-inch diameter and six feet length were taken and at the bottom of each tube 250 double seeds, containing about 105 living Pink-Bollworms were placed in January 1929. In tube No. 1 the infested seeds were covered with one foot deep layer of sound seeds, in tube No. 2 with a layer two feet deep and so on. The sound seeds were examined thrice, *i.e.*, on 27th June, 30th July and 28th August, 1929 and the living and dead caterpillars, pupæ and moths found in them were removed and their number was recorded (Table XXV). The figures so obtained indicate that all the moths formed from caterpillars which pupated at the bottom of the seed-stores may not be able to reach the top.

As regards the Pink-Bollworms in seed stored in gunny bags, it was observed that *a large number* of them was able to crawl through the seed, but most of them were unable to work their way out of the bag. The moths formed were all unable to escape.

TABLE XXV.

Emergence of Platyedra *moths from double seed placed at different depths under sound cotton seed (Lyallpur, January 1929).*

Date of examination (1929)	Depth at which the infected seeds were placed	Number of moths, pupae and caterpillars found					
		On the top of seed heap	Inside seed-heap, at depths 1 to 5 feet from top.				
			1 foot	2 feet	3 feet	4 feet	5 feet
27th June	1 foot	0	1 DM 1 LP	—	—	—	—
	2 feet	0	0	4 LM 1 LP	—	—	—
	3 feet	1 LM	1 LP	0	1 DP	—	—
	4 feet	1 LM	1 DM 3 LP 2 DC	2 LC	1 LP	1 DM	—
	5 feet	1 LM	2 DM 1 LP	1 LP	1 LP	0	1 LP
28th June to 30th July	1 foot	6 LM	1 LP 6 EP	—	—	—	—
	2 feet	1 LM	0	3 EP	—	—	—
	3 feet	1 LM	0	0	0	—	—
	4 feet	7 LM	0	1 EP	0	1 LM 1 DM 1 LP 1 DP 5 EP	—
	5 feet	5 LM	0	0	1 DM	1 LP	3 EP
31st July to 29th August	1 foot	4 LM	2 EP	—	—	—	—
	2 feet	3 LM	1 EP	0	—	—	—
	3 feet	0	0	0	0	—	—
	4 feet	2 LM 1 DM	3 EP	0	0	0	—
	5 feet	1 LM 2 DM	0	0	0	0	0

REMARKS. L denotes living, D denotes dead, M denotes moth, P denotes pupa, E denotes empty pupal case, and C denotes caterpillar.

Secondly, it had been noticed that the seed placed in large godowns was not disturbed frequently and hence the moths emerging from pupae a few feet below the surface were not ordinarily seem to be able to crawl out of the seed. On the other hand, it was seen that petty stores in possession of cultivators or village shopkeepers were very carelessly kept, and every moth formed seemed to have a positive chance to reach the cotton fields. Moreover, these village seed stores were often daily disturbed as some portion of the seed was removed either for sale or for feeding cattle. This frequent disturbance helped the caterpillars or moths in the lower strata of the stored seed to come to the surface.

Conclusions.—From this brief survey it is quite clear that small stores of seed with zemindars or village shopkeepers are far more dangerous to the crop than big stores owned by merchants and ginners, and hence great attention should be paid to the village seed stores while attempting to control the pest. King and Giffard [1924, 1] have also arrived at the conclusion that the main source of infestation is seed-cotton and cotton-seed in store, in natives' houses.

The fact that a large number of caterpillars hibernate in cotton-seed clearly indicates that the destruction of Pink-Bollworm in stored seed is very important in the control of this insect.

(8) The Fate of Pink-Bollworms in the sown Cotton-seed.

Pink-Bollworms in seed kept for sowing.—As has already been pointed out the cotton crop in the Punjab is sown from the beginning of April to the beginning of July. During this period the Pink-Bollworms are still in the resting condition and the hibernating caterpillars are likely to reach the fields in the seed sown.

In regions where Pink-Bollworm is a serious pest, the seed kept for sowing often contains a large number of living Pink-Bollworms (see page 255 *et seq.*). In an average sample of seed, examined during April to July from Rohtak, Sialkot and Ferozepore, there were as many as 51 living Pink-Bollworms per seer of seed. Calculating at the usual seed rate of five seers per acre, the number of resting Pink-Bollworms sown along with the cotton seed may be as high as 250 per acre, and if the stock of the seed is badly attacked, the number may easily be as high as 1,000 or even more.

Survival of Pink-Bollworm in seed soun.—In the Punjab cotton is mostly broadcasted and in a few cases it is sown in lines. The seed is placed at about two to four inches below the surface and the first watering is usually given after four to six weeks. This practice is adopted on an average soil in the absence of rains. From the time of sowing to the time when the first watering is given, which is over one month, the caterpillars sown with the seed remain undisturbed in the field.

In order to obtain some information regarding the fate of the Pink-Bollworms under such conditions and their ability to make their way through the soil, certain experiments were conducted during 1929, the results of which are given in Tables XXVI and XXVII.

In the first series of trials, 200 infested seeds were sown in each of the eighteen plots, at each of the three stations, Rohtak, Sialkot and Lyallpur. In all three sowings

TABLE XXVI.

Pink-Bollworms surviving in seed sown on different dates at Rohtak, Sialkot and Lyallpur during 1929.

Plot Number.	Date of examination (1929)	Number of Pink-Bollworms surviving in									Remarks
		Seed sown in 2nd week April			Seed sown in 2nd week May			Seed sown in 2nd week June			
		Rohtak	Sialkot	Lyallpur	Rohtak	Sialkot	Lyallpur	Rohtak	Sialkot	Lyallpur	
1	June 1-15 .	0	0	0	0	7	0	0	—	—	In each plot 200 infested seeds were sown.
2	16-30 .	0	0	0	0	0	0	17	—	—	
3	July 1-15 .	0	0	0	0	0	0	9	—	—	
4	16-31 .	0	0	0	0	0	0	0	—	—	
5	August 1-15 .	0	0	0	0	0	0	0	—	—	
6	16-31 .	0	0	0	0	0	0	0	—	—	

TABLE XXVII.

Pink-Bollworms found on the surface of soil from infested seeds sown during 1929.

Date of examination		Number of Pink-Bollworms found on the surface of soil from						Remarks
		Seeds sown in 1st week April			Seeds sown in 1st week May			
		Rohtak	Sialkot	Lyallpur	Rohtak	Sialkot	Lyallpur	
April	16-30 . .	12	0	0	0	—	—	1. At each locality 1,000 infested seeds were sown and the area covered with a wire-gauze cage. 2. Figures given in parenthesis are those of moths.
May	1-15 . .	6	23(2)	0	19	73	0	
	16-31 . .	0	1	0	0	11(2)	0	
June	1-15 . .	0	0	0	0	0	0	
	16-30 . .	0	0	0	0	0	0	
July	1-15 . .	0	0	0	0	0	0	
	16-31 . .	0	0	0	0	0	0	
August	1-15 . .	0	0	0	0	0	0	
	16-31 . .	0	0	0	0	0	0	

were tried, the first sowing (Plots 1 to 6) was done in the second week of April, the second sowing (Plots 7 to 12) in the 2nd week of May and the third sowing (Plots 13 to 18) in the 2nd week of June, 1929. The first watering after sowing was given after six weeks, and then a watering was given every two weeks. The seeds of Plots 1, 7 and 13 were dug out and examined during the first fortnight of June; of Plots 2, 8 and 14 during the second fortnight of June and so on. The number of living Pink-Bollworms found from the seed of each Plot was separately recorded and is given in Table XXVI.

A very important fact brought to light through this experiment was that no caterpillar was able to survive till June inside the seed sown in April. In seed sown in May there were a few caterpillars which survived till the beginning of June, and in seed sown in June some caterpillars survived till the middle of July. The results in all three cases were similar, and it was strikingly manifest that the caterpillars sown along with the seed during April, May and June could not live inside the seed more than 4-5 weeks from the time the seed was sown. The moths originating from the seed sown in April and May are not likely to find cotton plants sufficiently advanced to provide food—flowers or bolls—for their progeny. In case of June sowing and all the sowings done later on, the caterpillars sown with the seed may remain *in situ* till the middle of July, and the moths from such caterpillars surviving till August may find the crop in a suitable condition to provide food for their progeny.

It remained to be determined if moths could actually emerge out of the seed sown. To determine this one thousand infested (apparently containing living worms) seeds were sown in the first week of April and one thousand seeds in the first week of May 1929 at Rohtak, Sialkot and Lyallpur in buckets that were covered with wire-gauze cages. From each cage the number of caterpillars and moths coming to the surface was recorded daily and the figures are given in fortnightly totals in Table XXVII. These show that during six weeks after sowing the caterpillars creep out of the seeds and a few moths also emerge. The observations further show that the caterpillars remained alive not longer than five weeks: they lived till the middle of May in the seed sown in April and till the end of May in the seed sown in the beginning of May. Unfortunately, sowing in June could not be done, but from these results it will not be wrong to infer that in case of seed sown in June the caterpillars may remain alive at least till the beginning of July. It may, however, be mentioned that the percentage of mortality of the caterpillars present in the seed was very high, as out of one thousand infested seeds the maximum number of caterpillars surviving was 86 (at Sialkot). Thus it will be seen that the caterpillars from seed sown in April could not live longer than the middle of June—a time at which almost all the caterpillars would ordinarily die through the effect of

sun-heat as has been already shown above. On the other hand, the caterpillars in the seed sown in the beginning of June could remain alive till the middle of July or later in case of late-sown seed. The moths emerging at this time of the year will be a source of real danger to the new crop.

In the Punjab the date of cotton sowing fluctuates considerably and conditions vary according to the locality. In the Canal Colonies, where cotton is mostly grown on irrigated lands and where the Pink-Bollworm is a minor pest, late (June and July) sowing is a rare factor. In the South-eastern and Eastern Punjab, where Pink-Bollworm occurs as a harmful insect and where cotton is mostly sown on *barani* lands, considerable area of cotton is sown during June and in certain cases even in the beginning of July. It thus seems that in tracts, where the Pink-Bollworm is a serious pest, late sowings are actually practised, while in tracts, where the insect is harmless, sowings in June and later are very rare if at all done. Thus the seed sown in June and later and infested with the living Pink-Bollworms, may be a serious factor in the incidence of attack.

Sun-heating to destroy Pink-Bollworm in seed.—Investigations have shown a very easy way of dealing with the hibernating caterpillars in seed. Exposing infested seed to sun-heat appears to be an economic method of control. It has been established that if seed is exposed in a thin layer to the direct rays of sun in April, May or June for three hours, when the temperature of the seed may go up to 55-60° C., all caterpillars resting in the seed would be killed without the germinating capacity of the seed being impaired. Similar results were also obtained by Willcocks (1916) in Egypt and King (1928) in Sudan. In short, it would be a profitable practice if the Punjab cultivators take to this cheap and simple method of disinfecting all the cotton seed for sowing or for feeding to cattle.

Conclusion.—The caterpillars in the seed sown, may, in some cases, be responsible for starting infestation.

The Role of Alternative Food-plants in Pink-Bollworm Infestation.

Cotton is undoubtedly the principal food-plant of the caterpillar of *P. gossypiella*, but the insect also feeds on a number of other Malvaceous plants such as:—*Abutilon indicum* (*atibola* or *kanghi-booti*), *Sida cordifolia* (*kharenti* or *ranghi booti*), *Althea rosea* (*gulkhaira*), *Hibiscus esculentus* (*bhindi*) and occasionally on *Hibiscus cannabinus* (*sankokera*). As will be clear from Table XXVIII, it is only rarely that Pink-Bollworms are seen feeding on any of these plants. Of the recorded host plants the insect seems to show preference for *A. indicum*, and *H. esculentus*. In addition to these alternative food plants Fletcher [1913] has mentioned that in India *Gelechia gossypiella*, Saunds., is found to a very small extent in the flowers and seeds inside the pods of *Hibiscus abelmoschus* (*mushkdana* or *kastari bhindi*).

It is evident that, while during summer the insect feeds and breeds in the alternative food plants in addition to cotton, during winter, when the caterpillars enter the resting stage, it is found mostly in the remains of the previous years' cotton and only rarely in other host plants. Thus we may safely conclude that the alternative food plants do not play an important part in the incidence of *P. gossypiella* attack.

TABLE XXVIII.

Attack of Pink-Bollworm on different food-plants.

Locality	Month	*Gossypium sp.*		*Abutilon indicum.*		*Althea rosea.*		*Hibiscus esculentus.*		*Hibiscus cannabinus.*		*Sida cordifolia.*	
		Number of bolls examined	Per cent. attack	Number of bolls examined	Per cent. attack.	Number of pods examined	Per cent. attack	Number of pods examined	Per cent. attack	Number of pods examined	Per cent. attack	Number of pods examined	Per cent. attack
1	2	3	4	5	6	7	8	9	10	11	12	13	14
Rohtak	*Year 1926.*												
	August . .	260	1·2	...	...	...	...	863	0	...	...	763	0
	September .	6,523	7·3	1,263	3·2	...	...	3,923	0	523*	0·2	3,592	0·1
	October . .	9,639	23·4	221	0	..	...	971	0	1,581*	0	1,002	0
	November .	7,797	29·8	1,187	0	...	...	4,205	0·1	8,838	0	5,274	0
	December. .	3,259	36·0	2,395	0	...	...	55	0	4,281	0	2,916	0
	Year 1927.												
	January . .	...	...	727	0	...	...	...	...	340	0	857	0
	February . .	...	...	2,096	0	..	...	...	...	...	...	1,563	0
	March . .	...	...	2,275	0	...	...	...	...	...	...	3,853	0
	April . .	...	...	1,520	0	...	...	...	...	...	...	2,668	0
	May . .	43**	0	5,368	0	...	...	...	...	...	...	3,203	0
	June . .	44**	0	3,610	0	...	...	...	...	...	...	3,092	0

	July . .	321**	6·2	6,819	0	...	...	...	...	...	...	6,446	0
	August . .	3,327	6·2	585	0·5	...	..	67	0	...	...	1,668	0
	September .	6,186	13·1	3,216	2·4	...	...	74	0	...	...	3,604	0
	October . .	5,989	35·2	5,611	1·2	...	...	...	...	1,626*	0	3,165	0
	November .	3,530	47·9	3,835	0·1	...	...	.	...	687*	0	2,383	0
	December .	865	55·8	3,770	0	...	...	...	...	1,194	0	4,658	0
	Year 1928.												
	January . .	.	...	2,807	0	...	...	...	...	...	...	2,351	0
	February . .	...	...	4,119	0	...	...	...	...	...	...	3,967	0
	March . .	...	...	4,138	0	...	...	...	...	...	...	1,962	0
	April . .	47**	0	3,811	0	.	...	...	...	...	...	1,798	0
	May . .	96**	0	2,866	0	...	...	...	...	...	...	2,761	0
	June . .	352**	0	2,659	0	...	...	...	...	...	...	1,833	0
	July . .	193**	0	705	0	598	0	...	...	...	...	315	0
	Year 1926.												
Sialkot .	August . .	1,124	1·6	...	...	...	...	2,868	0	...	...	...	...
	September .	2,855	1·4	39	0	...	...	640	0	346*	0	0	0
	October . .	5,372	6·1	486	0·4	.	...	594	0	300	0	...	...
	November .	3,887	17·7	665	1·2	...	...	643	0	606	0	...	...
	December .	2,442	23·9	651	0.3	...	...	465	0	640	0	...	...

Attack of Pink-Bollworm on different food-plants—contd.

Locality	Month	*Gossypium sp.*		*Abutilon indicum.*		*Althea rosea.*		*Hibiscus esculentus.*		*Hibiscus cannabinus.*		*Sida cordifolia.*	
		Number of bolls examined	Per cent. attack	Number of bolls examined	Per cent. attack	Number of pods examined	Per cent. attack	Number of pods examined	Per cent. attack	Number of pods examined	Per cent. attack	Number of pods examined	Per cent. attack
1	2	3	4	5	6	7	8	9	10	11	12	13	14
	Year 1927.												
	January . .	...	...	467	1·3	...	...	429	0	546	0	...	...
	February . .	...	...	952	0·1	...	...	230	0	503	0	...	...
	March . .	...	...	1,650	0·5	...	...	...	...	1,518	0	...	...
	April . .	...	...	1,592	0·3	...	...	...	...	204	0	350	0
	May . .	256*	0	1,106	0	109	1·0	50	0	...	...	662	0
	June . .	886**	0	599	0	831*	0	437	0	..	..	286	0
	July . .	257**	0·4	456	0	322*	0	150	0	...	...	138	0
	August . .	3,110	4·1	245	0	234*	0	1,546	0·3	...	...	...	...
	September .	7,150	13·3	1,286	0	43*	0	1,633	0	911	0	701	0
	October . .	6,241	25·3	1,725	0	...	...	1,045	0	562	0	529	0
	November .	5,433	36·4	1,838	0	66*	0	1,283	0	1,324	0·1	603	0
	December .	3,839	32·5	1,055	0	202*	0	422	0	1,140	0·2	576	0
	January . .	..	...	1,806	0·3	594*	0	208	0	1,708	0·6	...	...
	February . .	..	...	2,419	0·1	1,857*	0	...	...	1,788	0·8	...	...
	March . .	..	...	1,376	0.4	1,422*	0	...	...	1,914	0·5	...	...

Sialkot	*Year 1928.*												
	April . .	...	...	2,348	0	748	0	...	...	1,151	0·5	...	...
	May . .	481**	0	753	0	538	0	...	...	275	0	...	...
	June . . .	122	0	906	0	856	0	...	...	...	...	...	...
	July . .	343	0	275	0	1,075	0	...	...	...	...	...	...
Lyallpur	*Year 1926.*												
	August . .	940	0·5	...	...	259*	0	22*	13·6	479	0	20	0
	September .	5,801	0·7	...	...	677*	0·1	314	0·6	827	0	1,371	0·1
	October . .	7,577	2·6	...	...	874*	0·5	383	0	1,666	0	3,954	0·1
	November .	7,804	8·3	...	...	412*	0	272	0·3	2,494	0	1,836	0·2
	December	7,383	7·3	...	...	1,221	0·2	542	0	1,654	0·1	3,302	0·4
	Year 1927.												
	January . .	...	...	...	...	320*	0	...	...	...	...	2,054	0
	February . .	...	...	...	...	690*	0	...	...	...	...	965	0
	March . .	...	...	...	...	870*	0·3	...	...	...	...	1,390	0
	April . .	...	...	...	...	1,320*	0·2	...	...	...	...	2,141	0
	May . .	21**	0	...	...	2,916*	0·4	...	...	...	...	3,063	0
	June . .	83**	0	...	...	2,206*	0·3	...	...	...	...	1,613	0
	July . .	60**	0	...	...	1,331*	0·2	...	...	...	...	1,358	0
	August . .	2,540	0·4	...	...	375	1·9	629	0	...	...	2,086	0
	September .	3,113	1·9	...	...	863*	0·1	609	0·2	906	0	2,767	0

Attack of Pink-Bollworm on different food-plants—concld.

Locality	Month	*Gossypium sp.*		*Abutilon indicum.*		*Althea rosea.*		*Hibiscus esculentus.*		*Hibiscus cannabinus.*		*Sida cordifolia.*	
		Number of bolls examined	Per cent. attack	Number of bolls examined	Per cent. attack	Number of pods examined	Per cent. attack	Number of pods examined	Per cent. attack	Number of pods examined	Per cent. attack	Number of pods examined	Per cent. attack
1	2	3	4	5	6	7	8	9	10	11	12	13	14
	October. . .	4,154	8·6	...	...	251*	0	140	0	530	0	1,511	0
	November .	3,581	14·4	...	...	63*	0	92	8·7	652	0	443	0·7
	December .	3,378	12·8	...	...	468*	0	373	1·9	908	1·2	1,125	0·4
	Year 1928.												
	January . .	...	..	...	...	493*	0	45	0	530	0	1,093	0
	February . .	...	..	...	...	530*	0	...	...	...	...	...	...
	March . .	...	..	...	...	171*	0	...	...	...	...	...	...
	April . .	...	..	...	...	..	...	...	...	...	...	...	...
	May . .	75**	0	..	...	100*	0	...	...	...	...	...	...
	June . .	391**	0	..	...	460*	0	...	...	...	...	...	...
	July . .	319	0·6	...	...	135	0	193	0	296	0	...	...

Figures marked (*) are those of flower and flowers-buds and those marked (**) are of ratoon cottons.

Summary.

1. In the Punjab the life-cycle of Pink-Bollworm consists of two different types, the short-cycle and the long-cycle. In the first case the duration of each life-cycle varies from 19 to 37 days and there may be four broods of this insect from August, when the attack starts, to November when hibernation occurs.

2. In the second case the caterpillars hibernate. The period of hibernation extends to the next summer, normally it is up to July-August. The maximum duration of this brood so far recorded has been ten months.

3. The infestation of Pink-Bollworm on cotton is carried from one cotton crop to the subsequent crop through the moths developing from long-cycle caterpillars. The moths emerging up to the end of June cannot breed as the food supply is not available. The first brood of the worms that appears in the cotton fields is the progeny of moths emerging in July.

4. The possible winter quarters of this pest are in the remains of the last year's cotton crop and in the food plants other than cotton. These winter quarters are the sources of infestation for the next year cotton crop.

(a) *Bolls on plants left standing in the fields after the harvest.*—The bolls left on the cotton plant after picking either fall to the ground (before May) and get mixed with those shed during the cotton season (before December) or they are eaten up by the flock of goats and sheep that are often let into the fields to graze. Exceedingly few bolls are left on the plants and therefore the chances for those bolls harbouring resting caterpillars are very remote, at any rate, this can hardly be a source of infestation.

(b) *Fallen bolls lying on the surface of the soil.*—The Pink-Bollworm resting in fallen bolls may survive up to the end of February, and the mortality till that date may not exceed 33 per cent. During March and April, however, most of the fields, on which cotton grew are fully exposed to the heat of the sun, the resting caterpillars in bolls and *kapas* die in large numbers and by May they are all killed. If some moths do emerge prior to May, they cannot do any harm to the crop.

(c) *Bolls and seed buried under-ground.*—Some of the fallen material gets partly or totally buried under ground, and these buried bolls although they contain a number of living Pink-Bollworms, yet it seems very unlikely that under the Punjab conditions more than an occasional moth ever succeeds in emerging after the month of June. The moths emerging before July cannot be a source of danger to the cotton crop.

(d) *Bolls and* kapas *carried away by rats.*—Some of the fallen bolls and kapas are carried away by rats to their burrows, where the hibernating caterpillars are all eaten up.

(e) *Bolls on sticks stored for fuel.*—A number of resting caterpillars survive till July in dead and open bolls lying on the ground underneath a heap of sticks. Such caterpillars, though not in very large numbers, are likely to contribute towards the infestation of cotton.

(f) *Low grade cotton and heaps of patti kept in ginning factories.*—The observations show that this source of infestation, although not one of the principal factors, is undoubtedly an important subsidiary factor in starting infestation.

(g) *Stored* kapas *as source of infestation.*—Observations carried out in the Rohtak and Lyallpur districts show that the quantity of kapas left unginned after June is very small, both in the villages and in towns, and thus no danger can be apprehended from this source.

(h) *Stored cotton seed as source of infestation.*—Our observations in the Punjab go to prove that a large amount of seed remains undisposed of till June and this seed harbours a large number of living Pink-Bollworms. It appears that the main source of danger for wide-spread infestation is the seed stored in villages and in cities.

(i) *Sown seed as source of infestation.*—A number of Pink-Bollworms find their way to the fields in seed sown. In the Punjab cotton sowing continues from April to the beginning of July. The caterpillars in seed sown in April and May cannot survive after June, but those present in the seed sown in June may be able to come to the surface up till the middle of July or later in case of late-sown seed. The moths emerging at this time of the year will be a real menace to the new crop.

(j) *Alternative food plants.*—During winter hibernating caterpillars are rarely, if at all, found in the food plants other than cotton. Consequently alternative food plants do not play an important part in carrying infestation.

5. In short, the evidence collected so far shows that Pink-Bollworms resting in fallen bolls, etc. (lying on the surface of the soil or buried under-ground), bolls on sticks left standing in the fields, bolls, etc., carried away by rats and food plants other than cotton are not sources of infestation to the new cotton crop in the Punjab. The infection is most probably caused by the caterpillars resting in cotton-seed, cotton stick material and heaps of *patti* (refuse) accumulating in the ginning factories.

Observations regarding the control of Pink-Bollworm in the Punjab.

It is evident that little can be done when the insect has once established itself in a crop. The caterpillars living in the bolls are fairly efficiently protected from the attack of parasites and other enemies, and ordinary chemical and mechanical methods of control cannot be employed. Thus it follows that the control of Pink-Bollworm rests entirely on the successful application of preventive rather than remedial measures.

It is not necessary to adopt any control measures against *P. gossypiella* in the Canal Colonies and further West, natural agencies are effecting satisfactory control, but measures shall have to be adopted in South-Eastern and Eastern Punjab.

The observations made show that there is hardly any need for any steps being taken to get cotton sticks pulled up before a certain date, but efforts should be made to get all sticks and bolls that have been removed from the field, burnt before the end of May.

The crop, as has been shown, is infected from the long-cycle moths, thus success in control of Pink-Bollworm consists in destroying the pest during its period of hibernation. The investigations carried out establish the fact that a large number of Pink-Bollworms successfully pass the resting stage in cotton seed, stored sticks and *patti* in the ginneries.

It should not be difficult to get gin trash and cotton sticks burnt, but treatment of cotton seed is a difficult matter. Methods of control are of little avail unless they are applied on a very large scale.

The seed ginned in the villages is usually fed to cattle and is often consumed before April, and so the large amount of seed found in the villages during winter months has no practical bearing on the control of seed-worms, since the infection of the Pink-Bollworm in the Punjab starts in July-August and it is the caterpillars present in the seed after June that have to be destroyed. On the other hand, it is observed that the seed found in villages after April is, in majority of cases, obtained from the cotton ginning factories. Thus we see that the seed which is responsible for the infection of the new cottons is distributed from the ginning factories. If any attempt is to be made to disinfect the seed against Pink-Bollworm, it can best be effected in the ginning factories.

Cotton merchants and owners of ginning factories, who are not directly interested in the welfare of zemindars, would not treat their seed for Pink-Bollworm, because in so doing they have to incur an extra expenditure without any material gain to them. This indifference of the ginners is likely to be the greatest difficulty in a complete eradication of Pink-Bollworm in cotton-seed.

It is, therefore, recommended that by law every ginning factory should be made to fit up an apparatus for treating seed, and all seed stored should

be treated. While inspecting factories it should be the duty of the inspecting officer of the Agricultural Department to discover if any seed contains living Pink-Boll-worms. This measure shall be necessary only in South-Eastern and Eastern Punjab. A similar procedure is in existence in Egypt, where heat treatment is practised [Min. Agri. Egypt, 1923].

Zemindars should be encouraged to buy treated seed and the Government may consider the advisability of giving subsidy for good seed.

Village shopkeepers and zemindars should be encouraged to sun-heat all seed in April to destroy the pest.

Appendix I.

Area, out-turn and value of cotton crop for the last five years in the Punjab.

Year	*Desi* or American cotton	Sown area (million acres)			Production of cleaned cotton (million bales)			Approximate value of cleaned cotton (Crore rupees)		
		Irrigated	Unirrigated	Total	Irrigated	Unirrigated	Total	Irrigated	Unirrigated	Total
1924	*Desi*	1·1	0·3	1·4	0·4	0·1	0·5	8·8	1·2	10·0
	American	1·0	..	1·0	0·3	..	0·3	9·7	..	9·7
	Total	2·1	0·3	2·4	0·7	0·1	0·8	18·5	1·2	19·7
1925	*Desi*	1·3	0·3	1·6	0·3	0·1	0·4	6·6	0·8	7.4
	American	1·1	..	1·1	0·4	..	0·4	7·5	..	7·5
	Total	2·4	0·3	2·7	0·7	0·1	0·8	14·1	0·8	14·9
1926	*Desi*	1·1	0·3	1·4	0·2	0·1	0·3	3·3	0·5	3·8
	American	1·1	..	1·1	0·2	..	0·2	3·5	..	3·5
	Total	2·2	0·3	2·5	0·4	0·1	0·5	6·8	0·5	7·3

NOTE.—It is of interest to note that similar conclusions have been reached independently for the United Provinces by Richards [1927, 1928, 1929].—Editor.

Area, out-turn and value of cotton crop for the last five years in the Punjab—contd.

Year	*Desi* or American cotton	Sown area (million acres)			Production of cleaned cotton (million bales)			Approximate value of cleaned cotton (Crore rupees)		
		Irrigated	Unirrigated	Total	Irrigated	Unirrigated	Total	Irrigated	Unirrigated	Total
1927	*Desi*	1·0	0·1	1·1	0·3	..	0·3	5·1	0·3	5·4
	American	0·7	..	0·7	0·2	..	0·2	4·7	..	4·7
	Total .	1·7	0·1	1·8	0·5	..	0·5	9·8	0·3	10·1
1928	*Desi*	1·4	0·1	1·5	0·3	..	0·3	..	..	..
	American	1·0	..	1·0	0·2	..	0·2	..	..	..
	Total .	2·4	0·1	2·5	0·5	..	0·5	..	..	..

APPENDIX II.

Export of cotton-seed from the Punjab.

PART I.

Total quantity (in hundredweights) exported in each official year 1915-16 to 1919-20.

1915-16.	1916-17.	1917-18.	1918-19.	1919-20.
19,087	10,017	9,336	21,317	1,070,589

PART II.

Quantity exported in maunds from different parts of the Punjab during the year 1918-19.

Where exported	Delhi City	Rest of Cis-Sutlej territory	Territory between Sutlej and Jhelum	Territory between Jhelum and Indus	Total
United Provinces . . .	14	2,441	318	75	2,848
Rajputana and Central India .	950	14,670	3,696	0	19,316
Karachi (for foreign countries)	0	1,240	3,794	0	5,034
Other places . . .	0	365	1,427	24	1,816
Total .	964	18,716	9,235	99	29,014

APPENDIX III.

List of rotations with cotton practised in the Punjab.

Two years rotations	Three years rotations	Four years rotations
1. Wheat, cotton . . .	1. Wheat, fallow, cotton . .	1. Wheat, wheat, *toria* cotton.
2. Maize and *senji* mixture, cotton	2. Wheat, gram, cotton . .	2. Sugarcane, wheat, *toria*, cotton.
3. Cotton, cotton . . .	3. Wheat, *toria*, cotton . .	.....
.....	4. Wheat, maize and *senji* mixture, cotton.	.....
.....	5. *Juar* and *guara* mixture, sugarcane, cotton.	.....
.....	6. Maize and *senji* mixture, sugarcane, cotton.	.....
.....	7. Maize, wheat, cotton . .	.....
.....	8. Sugarcane, maize and *senji* mixture, cotton.	.....
.....	9. Maitha (*senji*), sugarcane, wheat, cotton.	.....

APPENDIX IV.

Maximum temperature in the Punjab during 1927 to 1929.

	Highest maximum shade temperature (F.)														
	March			April			May			June			July		
	1927	1928	1929	1927	1928	1929	1927	1928	1929	1927	1928	1929	1927	1928	1929
1. Ambala . . .	95·6	95·0	100·6	105·6	109·0	105·9	113·2	116·6	116·2	113·6	110 0	115·0	106·2	110·0	110·6
2. Delhi	95·2	93·6	101·4	103·4	103·4	105·2	112·0	112·3	113·0	111·4	108·5	111·3	114·4	107·5	107·2
3. Hissar	100·9	97·6	103·2	107·5	109·6	107·3	115·9	115·2	114·6	115·7	113·5	114·3	115·7	109·3	109·9
4. Ludhiana . . .	96·0	95·0	98·7	104·3	107·0	106·5	113·5	115·0	115·5	113·7	111·0	116·9	109·7	112·0	111·3
5. Sialkot . . .	91·9	90·0	92·5	103·7	105·0	107·5	111·6	115·0	115·8	111·9	112·0	116·3	109·7	113·3	106·8
6. Lahore . . .	96·3	92·8	96·3	106·1	109·2	106·6	115·9	115·5	116·8	115·0	112·8	118·6	115·0	111·1	108·4
7. Rawalpindi . . .	86·6	91·0	90·5	99·7	100·0	100·6	108·2	107·0	112·7	117·1	109·0	116·6	109·4	109·0	109·3
8. Khushab . . .	93·0	91·0	97·0	106·0	104·0	106·4	115·0	115·0	117·0	114·0	113 0	119·0	112·8	112·0	111·4
9. Lyallpur . . .	94·4	89·0	95·0	104·3	105·0	106·2	113·2	114·0	113·5	114·0	112·0	115·0	110·5	109·6	109·0
10. Montgomery . .	99·2	94·0	98·1	105·5	107·0	107·0	115·9	114·0	115·0	113·2	112·0	115·0	113·5	111·0	109·8
11. Multan. . . .	99·9	95·0	102·4	110·3	112·0	109·6	118·9	117·0	116·5	117·6	113·0	118·7	117·4	115·0	114·4

APPENDIX V.

Rainfall during 1924 to 1928 in the Punjab.

Rain gauge stations	Rainfall in inches																			
	1924				1925				1926				1927				1928			
	January to March	April to June	July to September	October to December	January to March	April to June	July to September	October to December	January to March	April to June	July to September	October to December	January to March	April to June	July to September	October to December	January to March	April to June	July to September	October to December
I.—SOUTH-EASTERN PUNJAB																				
1. Gurgaon . . .	3·3	2·2	28·0	3·4	0·1	8·2	15·3	0·9	2·8	2·6	24·1	0	2·1	2·8	16·1	2·1	2·8	1·8	5·0	2·2
2. Rohtak . .	3·2	3·0	15·8	4·0	0	6·7	13·9	0·8	1·8	4·1	16·5	0·1	1·2	0·8	17·2	1·9	1·7	2·4	10·9	0·9
3. Karnal . . .	3·4	0·9	30·4	2·5	1·3	15·7	22.4	1·0	3·2	2·2	19·9	0·2	4·1	0·8	16·8	4·9	4·3	1·9	14·0	1·8
4. Ambala . . .	4·5	1·0	32·8	1·9	0·6	8·0	20·6	0·7	3·8	2·2	21·1	1·2	4·7	1·8	18·1	4·9	2·9	2·2	15·8	3·0
5. Jullundhar . .	4·4	0·5	15·9	1·5	1·5	2·6	26·8	0·1	4·5	1·7	18·4	0·2	3·1	3·0	15·3	1·3	5·0	2·2	7·9	2·1
6. Ludhiana . . .	3·2	0·5	16·6	1·3	0·3	5·8	16·4	0·7	3·5	2·1	28·2	0·3	3·5	1·1	13·3	2·6	2·7	2·0	10·5	2·1
7. Ferozepur . . .	3·4	1·0	13·4	1·2	0·6	3·2	19·5	0·3	2·3	1·8	11·6	0	1·1	0·6	9·1	1·2	0·5	2·4	16·8	1·5
8. Hissar . . .	3·2	0·6	7·7	2·9	0	4·6	6·8	0·2	1·5	4·1	23·3	0	1·6	0·5	12·1	2·0	1·2	2·9	9·6	2·4
AVERAGE .	3·6	1·2	20·1	2·3	0·5	6·8	17·7	0·6	2·9	2·6	20·4	0·3	2·7	1·4	14·8	2·6	2·6	2·1	11·3	2·0
II.—EASTERN AND NORTHERN PUNJAB.																				
9. Hoshiarpur . .	7·5	0	17·9	1·8	1·9	6·3	30·4	1·5	2·5	1·2	25·5	0·7	2·8	5·3	18·4	3·2	2·4	1·6	18·1	2·1
10. Gurdaspur . . .	5·3	0·9	32·9	2·5	3·2	7·1	28·9	2·4	5·3	1·9	22·6	0·2	2·4	3·5	16·3	0·8	3·9	1·6	16·4	5·3
11. Amritsar . . .	2·8	1·2	21·5	2·3	1·4	2·5	13·8	0·9	3·5	2·0	23·1	0·3	1·3	2·0	7·8	1·1	1·2	2·0	8·2	2·5

12. Sialkot	6·1	2·0	22·4	4·0	2·0	11·5	22·8	2·2	5·7	6·4	31·7	0·5	3·0	2·4	17·0	0·5	2·8	1·5	23·3	5.5
13. Jhelum	7·8	2·6	28·8	2·7	4·1	6·7	15·4	1·9	4·5	5·9	18·4	0·2	2·4	3·8	11·7	0·9	3·5	3·5	9·0	4·6
14. Rawalpindi	8·2	6·6	23·1	0·9	3·7	6·8	23·6	2·0	11·3	5·2	40·2	0·7	6·7	3·0	16·3	0·5	4·8	2·4	14·2	7·2
15. Cambellpore	6·9	5·6	7·7	0·4	1·9	6·2	10·4	4·3	6·8	3·0	26·8	0·2	3·0	1·0	9·2	0·9	9·4	2·2	5·8	7·8
Average	6·4	2·7	22·0	2·1	4·0	6·7	20·8	2·2	5·7	3·7	26·9	0·4	3·1	3·0	13·8	1·1	4·0	2·1	13·6	5·0
III. CENTRAL PUNJAB.																				
16. Lahore	4·2	0·8	12·1	1·8	0·5	4·4	13·1	1·4	2·5	1·2	15·2	0·5	0·5	1·3	9·6	1·9	1·2	1·9	12·6	2·7
17. Gujranwala	3·6	2·3	12·6	2·9	1·0	7·6	15·9	1·8	4·9	5·4	16·4	0·4	1·4	2·4	5·6	1·3	2·6	1·4	15·6	3·7
18. Gujrat	4·7	1·9	19·0	2·4	1·4	10·7	17·3	2·2	5·0	4·4	24·6	0·1	1·8	5·2	10·1	0·5	2·1	1·5	14·6	3·8
Average	4·2	1·7	14·6	2·4	1·0	7·6	15·4	1·8	4·1	3·7	18·7	0·3	1·2	3·0	8·4	1·2	2·0	1·6	14·3	3·4
IV. WESTERN PUNJAB INCLUDING THE COLONY AREAS.																				
19. Mianwali	2·3	0·8	10·9	1·2	1·0	3·6	4·2	2·9	2·4	3·9	5·3	0	0·7	1·0	7·8	0·5	1·6	1·5	1·0	1·4
20. Shahpur	2·6	2·4	7·6	0·5	0·9	2·1	4·9	2·1	3·3	3·6	10·7	0·2	1·1	0·9	6·3	0·4	1·7	0·8	7·5	2·1
21. Jhang	2·6	2·2	7·4	0·3	0·4	3·5	7·5	0·7	0·8	1·8	10·0	0	0·6	0·6	2·6	0·4	1·4	2·9	2·6	1·3
22. Lyallpur	3·0	1·0	6·7	0·3	0·9	1·4	8·6	1·8	0	1·3	9·0	0	0·4	1·1	3·5	0·4	1·1	2·8	11·6	1·9
23. Sheikhupura	2·5	2·4	9·3	1·1	0·9	2·4	11·5	0·9	1·4	1·6	12·2	0·1	0·1	1·2	5·2	1·0	0·9	0·6	12·6	1·9
24. Montgomery	1·6	1·7	6·0	0·7	0·3	1·5	7·0	0	1·1	1·6	9·7	0·1	0·6	1·1	3·7	1·0	1·0	1·9	7·2	1·2
25. Multan	1·6	1·4	8·1	0·3	0	1·9	1·7	0	0·8	3·0	2·8	0·1	0·2	0·4	3·6	0·6	0·4	0·2	1·4	1·4
26. Muzaffargarh	1·2	1·3	15·2	0·5	0	1·7	2·6	0	0·5	1·9	2·6	0	0·2	0·9	1·9	0·3	0·5	0·2	2·2	0·2
27. D. G. Khan	2·5	1·4	8·0	0·4	0	1·6	2·1	0·1	0·6	3·6	1·8	0	0·1	1·1	1·3	0·3	0·5	0·4	1·2	1·8
Average	2·2	1·6	8·8	0·6	0·5	2·2	5·6	0·9	1·2	2·5	7·1	0·1	0·5	0·9	4·0	0·5	1·0	1·3	5·3	1·5

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A PRELIMINARY NOTE ON STIGMA RECEPTIVITY IN CERTAIN SUGARCANE VARIETIES.

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In a sugarcane arrow the opening of the flowers and hence the emergence of the stigmatic branches occupies a period sometimes as much as seven to eight days. For hybridization work the arrow will need to be pollinated each morning as fresh stigmas are exserted; and observations on stigma receptivity are likely to enable cross pollination to be done in one operation in the case of varieties whose duration of stigma receptivity is longer than the period of the opening of flowers in the whole arrow. The observations detailed in the present note represent stigma receptivity tests made during the 1929 arrowing season with the varieties POJ. 100, POJ. 2364 and Vellai, and repeated again for confirmation during the 1930 season. During the latter season POJ. 2725 was also tested. The above varieties were selected for these tests as they have little or no pollen of their own.

Mercado [1926] working with the sugarcane varieties C. A. C 87, Badila, and Negros Purple states that "observations were made on the length of the time the stigmas remained fresh.....Just after the flowers opened, the fresh stigmas could be seen to have a 'syrupy secretion'.....After a time the stigmas lost the sticky secretion, causing their receptive power to cease". Observations on stigma receptivity have also been recorded for other crops, *e.g.*, Anthony and Harlan [1920] on barley; and Leding [1928] on date palm. Anthony and Harlan found that, on the sixth day, no pollinations brought about fertilization, and according to Leding there was a gradual decline to 23·2 percentage of fertilized blossoms in the date palm on the eleventh day. Weatherwax [1923] states that "the period of receptivity in the maize silks continues for two weeks or more, the silks continuing to elongate in the meantime if they are not pollenized".

For these tests the 'isolated' canes—artificially rooted according to the method developed at Coimbatore [Venkatraman and Thomas, 1926] were kept growing in

big earthen pots (height 16 in., diameter at top 18 in.) and located in separate sheds—each variety in a shed—quite separate from other such sheds and far away from the cane plots at the station to protect against unintended pollen. After making sure by careful examination that the stigmas were actually free from any pollen, the experiment was started. In the morning the flowers were emasculated bofore opening, and left undusted with pollen for the required period. The stigmas were then dusted with fresh pollen, and about two hours after dusting, stigmatic branches were removed, stained with cotton blue, and examined under the microscope for pollen germinations.

In the 1929 season fresh POJ. 2696 pollen was dusted on the stigmas of all the varieties under study, the dusting being done after emasculation on 2, 4, 8, 12, 24, 48 and 72 hours old stigmas. On examining under the microscope it was found that the dusted pollen had germinated in all the above-mentioned stigmas. Pollen was then dusted on seven days old stigmas of Vellai, and POJ. 100 ; and five days old stigmas of POJ. 2364, and on these also germinations were noticed. These tests were repeated during the 1930 season and the pollen was dusted on five or more days old stigmas. The results are detailed in the following table.

TABLE I.

Results of stigma receptivity tests, 1930.

Name of the variety	Date of emasculation	Date of dusting with fresh pollen	Name of the pollen parent	No. of stigma branches examined	Total No. of pollen grains on stigma branches	Total No. of germinations	Remarks
POJ. 2725	16th October 1930.	21st October 1930.	Co. 285 . .	8	720	354	
POJ. 2725	Ditto. .	24th October 1930.	*Saccharum spontaneum.*	10	477	280	Tips of stigmatic branches found drying. Lower portions receptive.
POJ. 2725	Ditto. .	27th October 1930.	Ditto. .	8	808	27	Two branches completely dry. A third one just beginning to dry but receptive.
POJ. 2364	17th October 1930.	22nd October 1930.	Co. 285 . .	8	829	281	Three branches dry.
POJ. 2364	Ditto. .	24th October 1930.	*Saccharum spontaneum*	6	851	382	Two branches drying up in patches.

Results of stigma receptivity tests 1930—contd.

Name of the variety	Date of emasculation	Date of dusting with fresh pollen	Name of the pollen parent	No. of stigma branches examined	Total No. of pollen grains on stigma branches	Total No. of germinations	Remarks
POJ.2364	17th October 1930	27th October 1930.	Saccharum Spontaneum.	6	329	121	Two branches drying up in patches. A third one completely dry.
POJ. 100	1st November 1930.	9th November 1930.	B. 3412 . .	8	265	128	
Vellai .	27th October 1930.	1st November 1930.	Ditto .	6	720	322	
Vellai .	30th October 1930.	8th November 1930.	*Saacharum spontaneum.*	12	48	27	Only one branch receptive. Others dry.

It will be seen from the above table that about thirty-four to forty-nine per cent. of the pollen dusted had germinated on five days old stigmas of Vellai, POJ. 2364, and POJ. 2725, and that on such stigmatic branches as had not completely dried, there were germinations on 8, 9, 10, and 11 days old stigmas of POJ. 100, Vellai, POJ. 2364, and POJ. 2725 respectively. Besides the above tests, a few flowers of the varieties Vellai, POJ. 2364, POJ. 2725 and B. 6308 were emasculated about twenty-four hours before opening and the stigmas were dusted with fresh pollen. The stigmatic branches were then examined under the microscope and it was noticed that the pollen dusted had germinated on the stigmas.

It has to be pointed out that in all the foregoing tests the observations were intended mainly to find out whether the stigmas were receptive to pollen germinations, that is to say, whether fresh and viable pollen, when dusted on the stigmas, would germinate. It is proposed to continue these observations during subsequent years to ascertain the length of time during which the flowers of the sugarcane remain receptive to fertilization.

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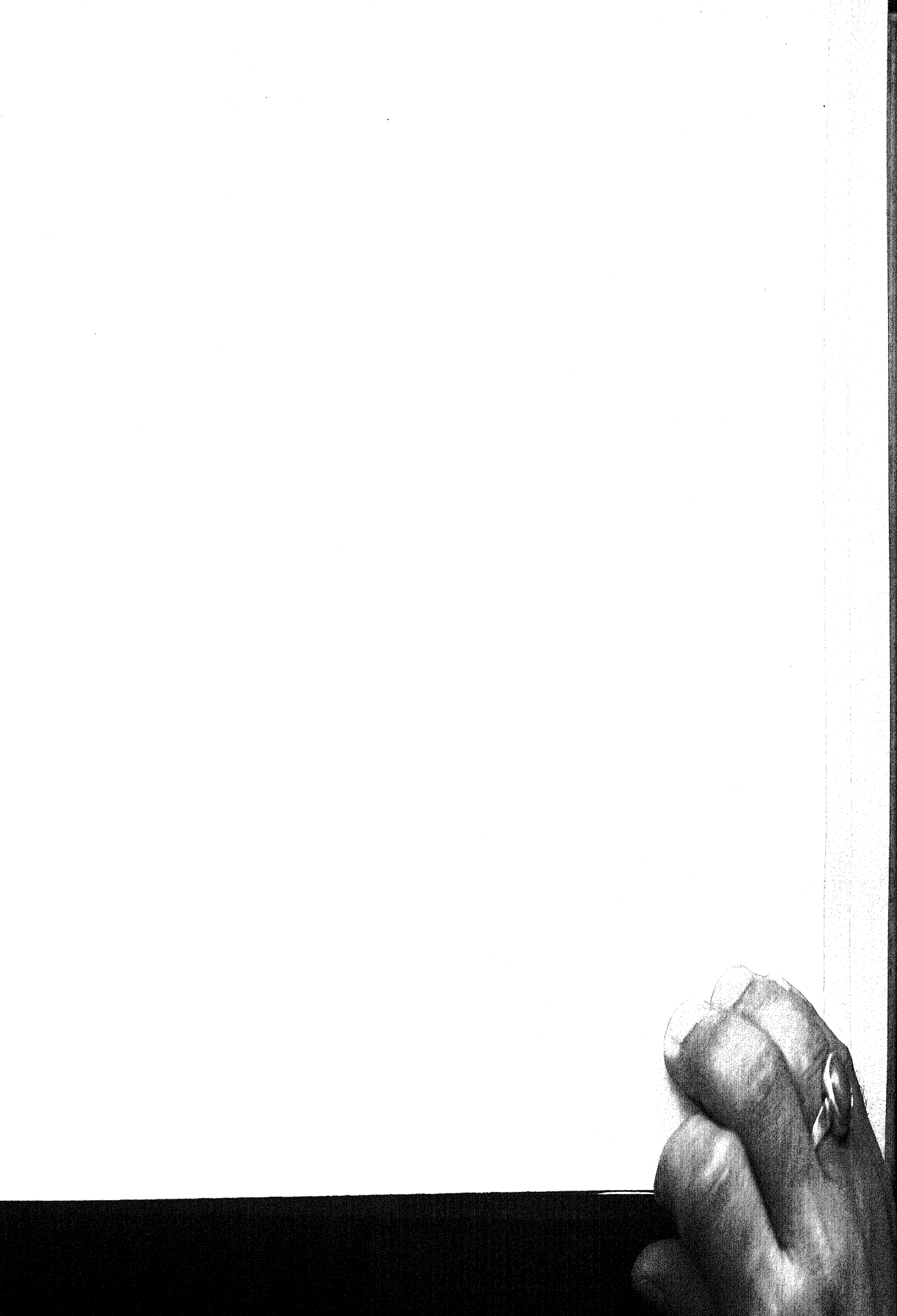

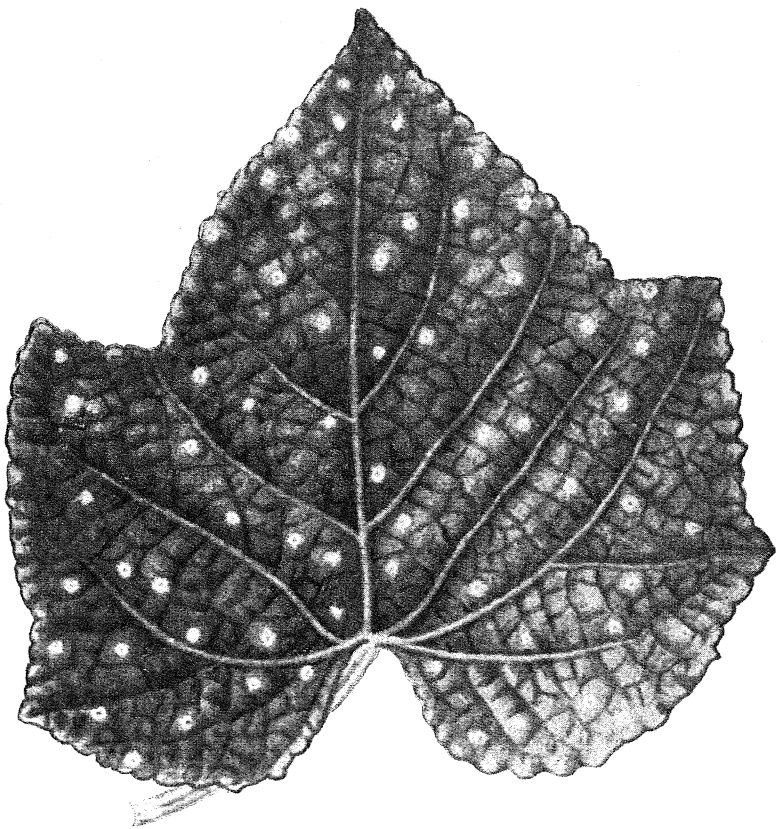

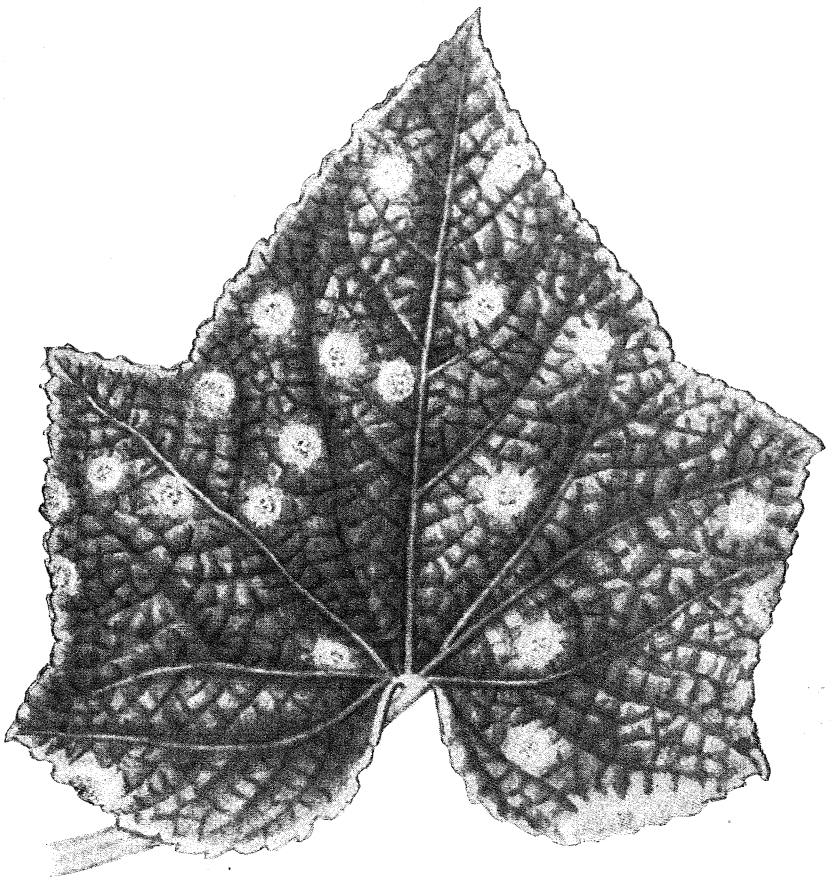

LEAFSPOT OF *KHIRA*.

FIG. 1. EARLY STAGE OF INFECTION.

FIG. 2. LATER STAGE OF INFECTION.

A NOTE ON BACTERIAL LEAF SPOT OF *KHIRA* (*CUCUMIS SATIVUS*).

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(Received for publication on 29th January 1930.)

With Plate XVI.

In July 1930 a leaf spot was noticed on the variety of *Khira* sown in February—March and grown under irrigation during the hot weather months. The spots were numerous, and had probably been present for some weeks; some leaves were covered with numerous spots, others were only slightly affected or unattacked. Affected plants were found in widely separated localities in and around Pusa. Similar spots were found, but in markedly fewer numbers, on an another variety of *Khira*, which is grown in the rainy season and without irrigation.

The spots were noticed only on the leaves, and are made conspicuous by a bright yellow halo. Two or more spots may unite, and form circular or angular brown areas. On the lower surface they appear smooth, thin, brown and water-soaked. Large areas of dead tissue may occur in places (Plate XVI).

Examination of affected material indicated that the spots were of bacterial origin. In microtome sections large numbers of bacteria were seen in the tissues adjoining the stomata. From diseased tissue an organism was isolated, which when suspended in water and sprayed or rubbed on the under surface of leaves of healthy plants, produced the characteristic spots in about four days. The organism could be re-isolated from these spots and successfully inoculated on fresh material.

DESCRIPTION OF BACTERIUM PRODUCING THE LESIONS

Short rods, 0·5-0·7 $\times$ 0·7-1·5 μ; motile by a single polar flagellum; in stained preparations from agar cultures it is found singly, in pairs, or in short chains; gram negative; spores absent; produces a little slime; colonies on ordinary agar convex, round, yellow, with internal concentric markings; liquefies gelatine slowly; strong diastatic action on potato; no gas formation from glucose, lactose, sucrose; no growth in Cohn's solution: moderate growth in Uschinsky; milk

slowly curdled and peptonised, some reduction of litmus.

This description agrees with that of *Bacterium cucurbitae*, which produces similar lesions on cucurbita, except in the reduction of nitrate and indol production. [Bryan, 1926 ; Elliot, 1930].

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ABSTRACT

Studies on the Transport of Nitrogenous Substances in the Cotton Plant. V. Movement to the boll. E. J. Maskell and T. G. Mason. (*Memoirs of the Cotton Research Station, Trinidad, Series B,* No. 3, 1930. Published by the Empire Cotton Growing Corporation.)

A 1. On the basis of earlier work, a tentative picture of the transport of carbohydrates and organic nitrogen is put forward as follows. For nitrogen as well as for carbohydrate transport there seems to be a gradient basis. For carbohydrates the head in the leaf is apparently reducing sugars, while for nitrogen the head is residual N. Within the sieve-tubes all the soluble carbohydrates and all the labile forms of nitrogen, including protein, should contribute to longitudinal transport, the part played by each depending on the effective concentration gradient maintained, and probably also on the diffusion constant. The machanism (possibly protoplasmic streaming) which is responsible for accelerating diffusion along the sieve-tubes should act impartially on all materials that are free to move. Movement from the sieve-tubes into other tissues and *vice versa,* is presumably confined to crystalloid substances, and in the case of nitrogen there is some evidence suggesting that residual N is the most important fraction. The rate of movement out of the sieve-tubes should depend on the effective gradient of exit maintained.

2. In the present paper we consider this picture of transport in relation to some aspects of the uptake of material by the boll.

B 1. In the first experiment a study is made of the effect of removal of flower-buds and bolls on the carbohydrate and nitrogen content of the leaves and the stem tissues.

2. Removal of flower-buds and bolls was followed by an increase in concentration of carbohydrates and of nitrogen, not only in the bark, but also in the wood and the leaf. Removal of a ' sink ', the flower-buds and bolls, is thus similar in its effects to the isolation of another ' sink ', the roots, by ringing the main-axis at ground level ; and the results confirm the general conception of a gradient basis for the transport of nitrogen and carbohydrates.

3. The percentage increase in nitrogen content was greater than that in carbohydrate content.

4. Polysaccharides account for a large part of the carbohydrate response, but total sugars also show a well-marked response, mainly due to sucrose. Protein N responds particularly in the leaves and in the upper region of the bark. Crystalloid N shows a well-marked response in all regions, and the percentage increase in crystalloid N is, in general, greater than that in protein N. In the leaves the crystalloid N response is mainly residual N ; residual N responds also in bark and wood, but except in the upper region of the wood the increases are small. The greater part of the crystalloid N response in the stem-tissues is due to asparagine. Nitrates are almost unchanged in the leaves, but show a fall in bark and wood of the upper region.

The results are in most respects similar to those obtained on ringing the stem near its base.

C 1. In the second experiment an attempt was made to elucidate the method of carbohydrate and nitrogen uptake by the boll. The uptake of carbohydrates and of nitrogen, and the

drift of sap concentrations, were followed for seven days in fertilized and unfertilized bolls. Ovules and carpels were handled separately.

2. A marked difference as between fertilized and unfertilized bolls, in uptake of carbohydrates and nitrogen, and a definite divergence in the march of sap concentrations of certain compounds, became apparent in both ovules and carpels on the fourth day after anthesis.

3. Two types of change are distinguished as likely to lead to the increased uptake by the fertilized bolls: (1) an increased *rate of utilization* of the mobile compounds (*i.e.*, compounds that enter the ovules and carpels from the sieve-tubes); (2) an increased *ease of entry* for these compounds. In the first case the concentration of the mobile compound in the growing organ diminishes, the gradient of entry steepens, and the rate of uptake increases. In the second case the rate of movement for unit gradient of entry increases, the concentration in the organ increases, and transformation (growth) becomes in consequence more rapid. If both factors operate there may be no change in concentration.

4. Ease of entry cannot be exactly measured, since we do not know the effective gradients of entry. But from (1) the amount of carbohydrate (or nitrogen) transformed during any time interval, and (2) the mean amount present during that time interval, of any compound that is assumed to be the mobile compound, estimates may be obtained of rates of utilization. *Utilization indices* can be calculated in this way for each of the compounds studied; and information is also available in each case as to the change of sap concentration during growth.

5. Applying these criteria to the results obtained for the fertilized and unfertilized bolls, it seems probable that the increased uptake of carbohydrate by the fertilized ovules and carpels is due to an increased ease of entry of sucrose, coupled with an increased rate of utilization. The concentration of sucrose remains low during growth, and maintains approximately the same level in fertilized and unfertilized bolls. In the case of nitrogen, the results strongly suggest that the greater uptake by the fertilized ovules and carpels is due to a higher rate of utilization of crystalloid N, producing a lower concentration and therefore a steeper gradient into the ovules and carpels. In the ovules this increase in rate of utilization and decrease in concentration is shown by asparagine and residual N, but in the carpels by residual N only. From a consideration of the gradients into the boll during growth it seems probable that for both ovules and carpels the residual N fraction rather than asparagine, is the form in which organic nitrogen enters from the sieve-tubes. In addition to an increased rate of utilization of residual N there may also be some increase in ease of entry.

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(*Authors' Summary.*)

THE INTERNATIONAL YEARBOOK OF AGRICULTURAL STATISTICS.

The International Institute of Agriculture at Rome has recently published the 1929-30 edition of the International Yearbook of Agricultural Statistics.

This volume of about 800 pages is the result of the most extensive and detailed inquiry made in the domain of international agricultural statistics and constitutes a work of the greatest importance to all those who are interested in questions having a direct or indirect relation to production and commerce of agricultural products.

In the first part of the Yearbook are classified the figures for area and population in the years nearest to 1913 and 1929 for 220 countries: the presentation of these figures throws light upon the world situation from the geographical, political and demographical points of view during both the pre-war and post-war periods. The second part is composed of a series of tables comprising for nearly 50 countries the available data concerning the uses for which the total area is employed, the apportionment of cultivated areas between the different crops, agricultural production, numbers of the different kinds of live-stock and the products derived from them. In the tables constituting the third part of the volume, have been indicated for nearly 40 agricultural products, the area, production and yield per acre in each country during the last five years of the pre-war period and during each of the years from 1926 to 1929.

For each kind of live-stock, all available figures in the different countries have been grouped for the years 1913 and 1925 to 1929. A large part of the volume is devoted to statistics of the commercial movement of 42 vegetable products and 12 products of animal origin. The figures published relate to the imports and exports during the calendar years and for the cereals also during the commercial seasons.

It may be added that the tables of production and commerce not only specify details for each country but also the totals for the different continents and hemispheres and for the whole world, allowing the formation of general idea of the changes taking place during the periods under consideration in the area under each crop, quantities harvested and the commercial movement in each product.

The part devoted to prices contains the weekly quotations of 25 agricultural products on the principal world markets for the year 1913 and for the period January 1926 to June 1930. In the freights section will be found the quotations for the carriage of wheat, maize and rice on the most important shipping routes, and in the section reserved for fertilizers and chemical products useful in agriculture are

published statistics of production, trade and prices for 15 products. In the rates of exchange section are set out the rates on the New York Exchange for the most important currencies.

For the first time there have been introduced into the volume special chapters on the importance and distribution of the agricultural population, the distribution of agricultural holdings according to their size and mode of tenure and forestry.

The volume has also been enriched by a long introduction and chapter of explanatory notes.

ORIGINAL ARTICLES

ANNUAL OUTBREAKS OF RUSTS ON WHEAT AND BARLEY IN THE PLAINS OF INDIA.*

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Wheat in India suffers from all the three rusts (*Puccinia glumarum* Eriks. and Henn., *P. triticina* Eriks., and *P. graminis* Pers.) known on that host. The yellow rust (*P. glumarum* Eriks. and Henn.) and the black (*P. graminis* Pers.) are also common on barley but the dwarf rust of barley (*P. simplex*) is very rare. Oats in India are free from rusts.

On an average there are 30,500,000 acres under wheat and 7,000,000 acres under barley in India each year.

The greater part of the area under these crops lies in the Indo-Gangetic plain, Central Provinces, Sind and Deccan.

Both these crops are also cultivated in the hilly tracts of the area mentioned above, as well as in the Himalayas up to an altitude of nearly 10,000 ft. above sea-level.

Both wheat and barley are sown in October-November and are harvested in March-April on the plains, whereas the harvesting in the hills is done a couple of months later.

As far as India is concerned the season of the year which is critical for rusts is the intensely hot summer and not winter, as is the case with most of the wheat-growing countries.

For a period of nearly seven years the incidence of all the five rusts under report has been studied by the writer in the plains of the United Provinces as well as in the Kumaon hills.

Casual observations have also been made at suitable periods in the neighbourhood of Simla for purposes of verification of the data obtained.

* Paper read before the Mycology Section of the International Botanical Congress on August 23, 1930, at Cambridge.

The present position of the problem of annual outbreaks of rusts in India may be briefly stated as follows :—

A. Incidence of rusts on the plains.

(1) About the harvest time (March-April) there is very little of the viable material of uredospores on the plains. All attempts to grow rusts, after the end of April, have failed at Agra even in shade, and this is in agreement with previous observations about United Provinces.

(2) It is almost impossible for the uredospores to survive after the harvest, on the plains of India, where the heat of summer is so intense that the maximum temperature in shade may be well above 110°F. for several weeks during May and June, over the greater part of the area under cultivation.

The above statement has been well corroborated by the results of experiments conducted with Hearson's 9 compartment incubator, in order to study the influence of summer temperatures on the viability of fresh uredospores.

(3) That explains why crops sown on the plains are free from rusts normally up to the middle of January each year, *i.e.*, two to three months from the time they are up. Yet the temperature on the plains is quite favourable for the growth of rusts from the middle of October onwards. Wheat inoculated at Agra with uredospores of brown rust brought down from the hills in specimen tubes in October developed pustules within a week.

(4) It is right therefore to conclude that, at the time when these crops are sown (October-November), there is no local source of infection on the plains of India. A few self-sown plants that may be present in the fields are invariably free from rusts, besides the alternate hosts are not found on the plains.

B. Incidence of rusts in the hills.

(5) Conditions in the hills are different, where on account of a comparatively mild summer, uredospores of rusts survive on self-sown plants and tillers during the critical period. Viable uredospores of rusts of wheat and barley have been found by the writer several times during summer at Muktesar (7,600 ft. above sea-level), where the average temperature during May-August, the hottest part of the year, is 20-30°F. lower than that of Agra.

(6) The infection of the new crops at such places in the hills, where uredospores are available on volunteers at the time of the sowing, does not need much of an explanation.

(7) Another fact to bear in mind is, that year after year rusts appear earlier on crops at the foot of the Himalayas than at places farther off. Plant to plant there is a severer attack at the foot of the hills in the month of January, when rusts are either absent, or are just appearing on the plains.

(8) On account of the obvious survival of uredospores in the hills during the critical period and earlier outbreaks of rusts every year at the foot of the hills, one may rightly conclude that it is a case of dissemination of rusts by wind to crops on the plains of India.

Yellow Rust (*P. glumarum* Eriks. and Henn.).

It is interesting to note that although there is no alternate host known for this rust, its recurrence is the easiest to explain.

As stated before, this rust survives the summer in the uredo-stage on self-sown plants in the hills at an altitude of nearly 7,000 ft. and above, and there is plenty of this rust at the time of the sowing.

After the infection of the new crop in the hills, the mycelium of this rust seems to grow by fits and starts during November-December, on account of the severely cold winter. Following a comparatively long incubation it breaks out in December-January. At the higher altitudes this is the only rust found up to the end of March as it stands cold better than the other two. It is probable that outbreaks of this rust on crops at Muktesar and places similarly situated lead to rust infection on the plains due to wind-blown uredospores.

Brown Rust of Wheat and the Black Rust of Cereals.

A few species of *Thalictrum*, the recently discovered alternate host for *P. triticina* and *Berberis*, the alternate host for *P. graminis*, are found in India in the hills. Aecidia on *Thalictrum* are rather rare and most of the æcidial material occurring on *Berberis* is caused by *Aecidium montanum* showing characteristic " witches-brooms ". Barclay has recorded the occurrence of æcidia on *Thalictrum* and *Berberis vulgaris* in India during July and August, but there is no evidence to show that they are connected with brown rust of wheat and the black rust of cereals respectively.

So far the writer has not come across æcidia on either of these hosts in the area that has been under observation in Kumaon and Simla hills.

Inoculations made with æcidiospores from *Berberis aristata* and *Berberis lycium* have given negative results in each case.

Viable uredospores of both these rusts, however, are found in the hills during the critical period.

It is interesting to note that these rusts appear on the plains by the beginning of February, *i.e.*, one-and-a-half to two months earlier than at Simla, or Muktesar, where they have not been found even by the end of March.

It is clear therefore that æcidia found in the hills during March-August have no direct part to play for crops on the plains. The results of observations made so far suggest that the source of infection for crops on the plains in the case of both these rusts spreads from lower altitudes where, on account of a mild winter, uredospores occurring at the time of sowing may cause outbreaks on the new crops rather early in the season, and the infection may then disseminate to plains in January-February.

At the foot of the hills near Nepal both these rusts were observed this year as early as the end of January, and it is proposed to extend the work to that territory soon.

The Imperial Council of Agricultural Research in India have recently accepted a scheme of investigations on cereal rusts, and work on the life-historie sof brown rust of wheat and the black rust of cereals is already in progress at two laboratories in the hills.

The Meteorological Department of India and the Royal Air Force at Ambala have kindly agreed to help in the study of rust dissemination. A few preliminary tests were made early this year, with slides exposed in aeroscopes and those sent up on hydrogen balloons, and the results were promising.* Uredospores of black rust were caught at Agra on a slide sent up on a balloon and on another exposed in an aeroscope three and two weeks respectively before that rust appeared on the crops. One of the slides exposed at Lyallpur caught spores of brown rust two weeks before it was noticed on the wheat crop.

With the facilities that are now available, the writer hopes that further work will fill up the gaps in our knowledge of the recurrence of rusts in India before long.

Damage done by Rusts and the Means of combating them.

According to an estimate made nearly 25 years ago, the annual loss in India due to rusts on wheat alone comes to Rs. 40,000,000, *i.e.*, £3,000,000 or so.

The absence of suspected alternate hosts on the plains, and the inability of uredospores to survive the summer over nearly 95 per cent. of the total area under wheat and barley, offer a unique opportunity for measures of control in India.

The data obtained so far clearly indicate that the foci of infection in the case of all the rusts under report lie in the hills.

* The mechanism of the 'Spore Trap' used for this purpose is explained in a Note, by Mr. G. Chatterjee, Meteorologist in charge of the Upper Air Observatory at Agra, published on p. 306 of this Journal.

Destruction of volunteers and tillers after harvest and before sowing in the hills seems to be one effective way of dealing with the situation.

Still more effective should be the suspension of cultivation of wheat and barley for two to three years in the hills which occupy hardly two to three per cent. of the entire area under these crops in the country. This method would be impracticable without the co-operation of the neighbouring States that own a considerable part of the hilly tract.

The only other way of checking the spread of rusts in the hills and thereby saving crops on the plains to a considerable extent, is to cultivate only rust-resistant varieties in the hills.

There is a pressing need therefore for investigations on the " biologic " forms of rusts on cereals and grasses in India. Information on the different forms that may be present in the country and their distribution should be of immense help in the selection and breeding of varieties suitable for cultivation in the hilly tract and at the foot of the hills. At present there is no such information available in India.

THE CEREAL-RUST PROBLEM IN INDIA.

BY

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(Received for publication on the 12th February, 1931.)

In view of the fact that only two years ago the writer published an account of his study of the "Annual recurrence of rusts on wheat in India" [Mehta, 1929] along with a review of earlier and contemporary work on the problem of cereal rusts done in other countries, a detailed discussion of the problem again would mean unnecessary repetition.

This article has been written at the instance of the Imperial Council of Agricultural Research and may be read in continuation with a paper on "Annual outbreaks of rusts on wheat and barley in India", which will be found elsewhere in this journal and was read by the writer as an invitation paper for a discussion on the "Dissemination of cereal rusts" at the last International Botanical Congress held at Cambridge in August, 1930.

It is unnecessary to stress the importance of investigations on cereal-rusts for a country like India where there are as many as 30,500,000 acres under wheat, and the barley crop covers another 7,000,000 acres each year.

The writer has already suggested the possible measures of control which will have to be adopted in course of time if a considerable part of the huge sum of Rs. 40,000,000 has to be saved out of an annual loss due to rusts of wheat alone in this country.

It is time we reviewed the problem in the light of recent work done in the United States of America, Canada and other important wheat-growing countries of the world. Work on similar lines will be necessary for a proper understanding of the problem as a whole in this country, before actual measures of control can be adopted over the entire area under wheat and barley.

The present state of our knowledge of the recurrence of rusts in this country may be summarized as follows :—

(1) Rusts of cereals are perpetuated from season to season largely by their uredospores which oversummer at different altitudes in the hills.

(2) As far as the plains are concerned, *Berberis vulgaris* and species of *Thalictrum*, the two alternate hosts for the black rust of cereals and the brown rust of wheat respectively, play little part in the yearly origin of those rusts.

Study of cereal-rusts in India has furnished one of the most interesting examples of the influence of weather conditions, particularly temperature, on the different parasites concerned. Data obtained so far about yellow rust in India have corroborated the observations previously recorded by the writer [Mehta, 1923]. This rust can stand cold very well but cannot oversummer in India except at higher altitudes. Outbreak of this rust on wheat and barley crops at higher altitudes as early as December-January each year suggests the probability of its dissemination to the plains by wind-blown uredospores.

With regard to the brown rust of wheat and the black rusts of wheat and barley, the writer has already recorded that the source of infection seems to spread to the plains from lower altitudes where, on account of a mild winter, uredospores of these rusts occurring at the time of sowing may cause outbreaks on the new crops rather early in the season. The above contention of the writer has been recently corroborated by work done at Almora, where both these rusts have survived in the open on miniature plots since the beginning of May 1930 and are alive up to the time of writing (23rd February, 1931). Recent work has also cleared up our doubts about the disappearance of the uredo-stage of these two rusts during winter at Muktesar, which is only 14 miles from Almora but is nearly 2,500 ft. higher (altitude 7, 600 ft.), and where the winter is intensely cold. The oversummering of brown and black rusts is not unlikely even at altitudes slightly lower than that of Almora (nearly 5,000 ft.) because they can stand warm weather better than yellow rust. At any rate the black rust, which can resist warm weather even better than brown, should be able to oversummer at altitudes of nearly 3,000—4,000 ft. above sea-level under moist conditions.

The data obtained so far clearly indicate that in India yellow rust survives in the uredo-stage all the year round at higher altitudes on account of a temperate climate. The brown and black rusts oversummer at higher as well as lower altitudes, but survive during winter only at the latter. The brown rust may survive as mycelium inside the host, but there is little likelihood of black rust surviving the winter at the higher altitudes because of plenty of snow.

In the light of the circumstances mentioned above the cereal-rust problem in India appears to be unique and should be far easier to tackle than is the case elsewhere. For instance, if our rusts are mainly propagated year after year by the uredospores, as seems probable, the serious complication in the way of breeding varieties of wheat resistant to brown and black rusts, on account of a large number of physiologic forms, does not arise. In the United States of America, on account of the hybridization on *Berberis vulgaris* which occurs over the greater part of the area under cultivation, there are 100 physiologic forms of black rust of wheat alone. In view of this serious difficulty in the way of breeding resistant varieties, the United

States government are spending large sums of money every year over the eradication of barberry bushes in order to save their cereal crops.

In India the absence of *Berberis vulgaris* and *Thalictrum* on the plains, which cover nearly 95 per cent. of the entire area under cultivation, is the most hopeful feature for measures of control.

If a careful survey in the hills ultimately establishes the fact, which seems probable, that *Thalictrum* and *Berberis vulgaris* (which occurs only at altitudes of 8,000—12,000 ft.) get rusted late in the season (March-May), and are therefore ineffective as far as the crops on the plains are concerned, the solution of this problem should be within sight in this country. The writer finds it difficult to understand as to how our crops on the plains could get rusted as early as December-January if the alternate hosts were responsible for fresh outbreaks of both brown and black rusts, because we know it definitely that these two rusts appear at higher altitudes nearly three months later. That should leave little doubt about the part which alternate hosts play at any rate as far as outbreaks on crops on the plains go. Consequently the survival of all the five rusts in the uredo-stage in the hills strikes one as a factor of outstanding importance in the annual recurrence of rusts on the plains of India.

Under the auspices of the Imperial Council of Agricultural Research a physiological study of all the rusts under report is in progress at the laboratories at Simla and Almora, where the life-histories of brown and black rusts are also under investigation. A study of the dissemination of rusts by wind was started in January, 1930, with the co-operation of the Meteorological Department, and the results obtained so far are very promising. It is proposed to extend the scope of this work by catching spores on kites at Agra in addition to the exposure of slides in aeroscopes, which is being done at present at six different stations over the area under cultivation.

Only recently a preliminary study of physiologic forms of rusts of wheat has been started by the writer with the object of finding out, in a general way, if there are many physiologic forms in this country, and if the forms occurring in various localities, including the hills, are different.

The following are the different aspects of the cereal-rust problem which still need intensive work in this country :—

(1) A thorough survey of the barberry situation in the hills and a study of the suspected connection between barberry and black rust as well as between species of *Thalictrum* and brown rust of wheat in nature.

(2) A combined survey of the regional distribution of all the five rusts in India and a survey of places, where oversummering of rusts is likely, in the near neighbourhood of all important areas of wheat and barley cultivation.

(3) A study of the different physiologic forms of rusts, their regional distribution in the hills and the neighbouring plains. Side by side with this work a study of the pathogenicity of the different physiologic forms on well-known varieties of Indian wheats would be of immense use for the selection of varieties suitable for cultivation and breeding purposes.

(4) Study of rust dissemination.

(5) When adequate information on the various aspects of the problem outlined above has been obtained and we know the physiologic forms that may be occurring in the country, the co-operation of plant-breeders would be indispensable for the breeding of resistant varieties suitable for cultivation in the hilly tracts of the country.

In India the control of rusts by the cultivation of resistant varieties should be more easily practicable than elsewhere because the perpetuation of rusts by uredospores is possible only over three to five per cent. of the entire area under wheat and barley. Consequently the cultivation of resistant varieties in the hills only should check outbreak of rust epidemics at those localities that are now working as foci of infection for crops on the plains.

The cereal-rust problem is an all-India concern, and being essentially a case of dissemination of infection by winds that know no territorial restrictions, it is hoped that the Indian States will offer all facilities they can in the investigation, and later on co-operate in the adoption of control measures.

At its last session, the International Botanical Congress made a strong case for investigations on cereal-rusts by passing unanimously a resolution drawing the attention of all cereal-producing countries of the world to the importance of the problem.

It will be clear from what has been stated above that at its present stage the problem under report needs a band of trained workers in India who should carry out investigations on the lines indicated above for a number of years.

In the United States of America and Canada work on this problem has been in progress for several years on lines of elaborate national schemes, and countries like Australia, Russia and Kenya have also undertaken investigations in the light of results obtained in the U. S. A. and Canada.

It is a problem full of promise, and when fully understood, should lead to results of incalculable value to agriculture in this country.

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A NOTE ON AN APPARATUS FOR CATCHING SPORES FROM THE UPPER AIR.*

BY

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(Received for publication on the 12th February, 1931.)

(With Plates XVII and XVIII.)

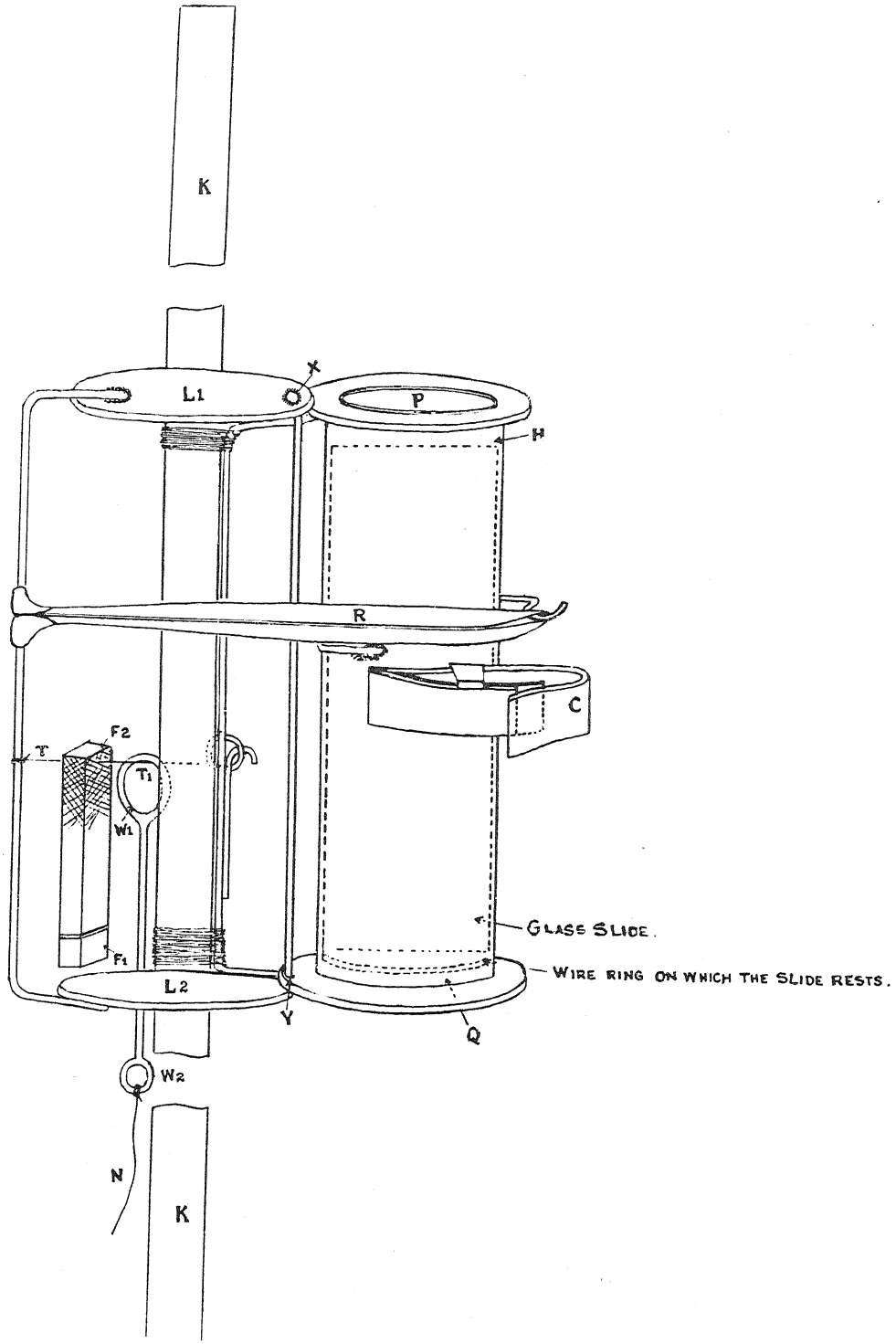
The apparatus (Plate XVII) consists of a cylindrical slide-holder H made of brass whose open ends P and Q can be closed by two circular flaps L_1, L_2, hinged about the line XY. The flaps are held in the position shown in the sketch, uncovering the ends of the slide-holder, by means of a thread T working against the tension of the rubber band R. The arrangement is such that when this thread is burnt or cut, the discs fly back under the tension of the rubber band to cover the ends of the slide-holder and are locked in position by a spring catch C.

The slide-holder is attached to the diametral stick (K) of a bamboo cage such that its length is parallel to the diametral stick and the cage is attached to a balloon with this stick vertical. (See E, Plate XVIII). During the ascent of the balloon the slide is thus exposed to a draught of wind.

The thread T which holds the flaps from covering the ends of the slide-holder passes through a fuse† F_1 F_2 whose rate of burning is approximately known. The length of this fuse F_1 F_2 is so adjusted that if it is ignited at the end F_1 just before the balloon is let off, it burns the thread shortly before the balloon has reached the height up to which the slide is required to be exposed. This adjustment is possible because the approximate rate of ascent of the balloon with its attachments is easily calculable.

* This note explains the mechanism of the "Spore Trap" which was used in hydrogen balloons for the study of rust dissemination, to which reference was made in the article on "Annual Outbreaks of Rusts on Wheat and Barley in the Plains of India", by Dr. K. C. Mehta, which appears on p. 297 of this Journal.

† For a method of preparing the fuse *vide* "An Upper Air Temperature Indicator for Use with Pilot Balloon", by G. Chatterjee, in *Gerlands Beitrage zur Geophysik*, Vol. 24 (1929), p. 351.



C—Catch to hold the flaps in position after once released. This prevents the finder from exposing the ends P and Q and also prevents dust, etc., from getting on the slide when the instrument lies on the field.

PLATE XVIII.

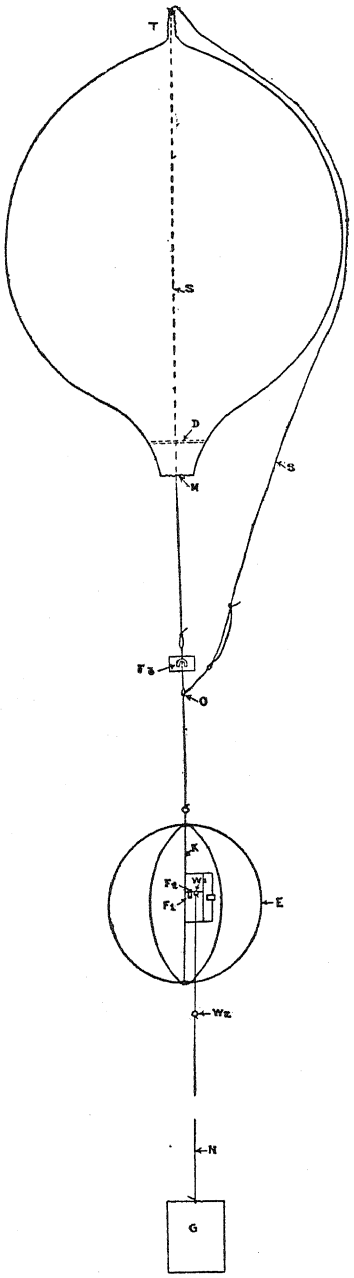


FIG. 1

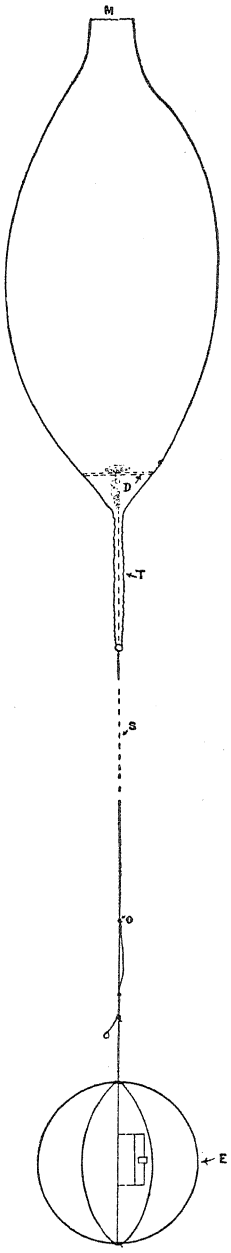


FIG. 2

A string N carrying a paper flag G at its end is attached to the thread T at the point T_1 by means of a wire looped at both ends (W_1 W_2). When the fuse burns the thread this flag is released. The distance between the mouth of the balloon (M in Plate XVIII) and the paper flag (G in Plate XVIII) is adjusted to a definite length, and gives us a baseline on which angular measurements can be taken. The balloon is followed by means of a theodolite, and readings of (1) the angular measure of the baseline on a graticule in the field of view of the theodolite and (2) angles of azimuth and altitude of the balloon are taken at definite intervals of time. These readings enable one to calculate the height of the balloon above ground at any instant. While following the balloon the instant at which the flag is released is also noted, so that the height through which the slide is exposed to the draught of air is easily calculated. By additional arrangements with an extra fuse it is also possible to begin to expose the slide after a known height above ground is reached.

The aim being to take up the spores-catcher to a desired height and not allow it to drift with the balloon further than is unavoidable, a special type of balloon developed originally by Mr. J. H. Field is used. For this purpose the balloon after reaching the predetermined height is made to empty itself of its hydrogen gas, with the consequence that the whole system descends under gravity down to the ground. Plate XVIII which gives a picture of the whole system just before ascent (Fig. 1), and during descent (Fig. 2), helps to explain the action of the balloon. Referring to these diagrams one can see that, to start with, the weight of the instrument and the cage is supported by the disc D which serves to close the mouth M of the balloon. The top of the balloon terminates in a long tubular piece T. A string S passes through this tubular piece and connects the top of the disc D with a point O in the balloon tail. Before the balloon is filled with hydrogen the tubular piece is squeezed and crumpled along its length to contract as much as possible, and its top-most end is tied securely to that part of the string S which is near it. Above the point O in the balloon tail is attached a fuse F_3 similar to that used with the spores-catcher but timed for a longer interval.

When the fuse F_3 burns the string above O, the weight of the cage and instrument is transferred to the top of the balloon by means of the string S. The weight of the instrument acting on the tubular piece stretches it, and this in turn acts on the string S and pulls the disc D of the balloon mouth which is now 'up' (*vide* Fig. 2, Plate XVIII). The process results in an escape of hydrogen, collapse of the balloon and downward motion of the whole system. (Fig. 2, Plate XVIII). As the fuse F_1 F_2 attached to the spores-catcher is timed for a smaller interval than the fuse F_3, the former will have worked and the ends of the slide-holder closed before the balloon begins to come down. The slide is thus kept protected from dust, etc., when

lying on the ground. A little vaseline spread over the flanges at either end of the slide-holder completely seals the ends for all practical purposes.

A notice promising a reward to the man who brings the balloon to the Observatory is attached to the cage so as to enable a recovery of the instruments sent up. The coming down of the white balloon with the instrument also helps the recovery of the balloon in as much as it helps to attract the attention of the finder.

The balloons used for the purpose are specially made at the Observatory out of Vulpro tissue.*

Upper Air Observatory,
Agra, 6th February, 1931.

* *Vide* Note by the author in *Nature*, Vol. 124, p. 793, 1929.

A STUDY OF CAUSES CONTRIBUTING TO THE LARGE VARIATIONS IN YIELDS FROM YEAR TO YEAR OF 4F COTTON IN THE PUNJAB.

BY

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(Received for publication on the 20th March, 1931.)

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(With Plate XIX and eleven diagrams.)

Introductory.

The fact that large variations in yield of 4F cotton occur from year to year is well known and the following table shows in round figures to what extent this variation can occur :—

TABLE I.

*Yield of 4F cotton per acre given in maunds.**

Year	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928
At Lyallpur . .	4	6-7	2	8-9	14	14	16-17	5	10	..
At Khanewal . .	..	..	7¾	12½	14½	14½	16	5¾	3⅓	1-26 seers.

The Lyallpur figures were obtained by taking the average yield of all the 4F plots in comparative varietal test experiments as given in the Annual Reports of the Experimental Farm of the Lyallpur Agricultural Station.

The water-supply and methods of cultivation on this station are good, and considerably above the average of the ordinary *zemindar*.† Under such circumstances it would ordinarily be expected that annual fluctuations would be considerably reduced in range. Yet the range is so great as to be remarkable.

Sir William Himbury [1929] has published figures of yield for the British Cotton Growing Association estate at Khanewal and these figures (given in Table I) also show the wide range of yields obtained. He remarks that "the cotton yields on the farm are generally from 50 per cent. to 100 per cent. higher than average yields on zemindari lands in the locality....." The cultivation and water-supply for this estate are good, and there is little variation in them from year to year.

"Failure" Years.

Within the last ten years there have been no less than 4 "Failure" years, namely 1919, 1921, 1926 and 1928, and two other years in which the crop failed partially, *viz.*, 1920 and 1927. The failures of 1919 and 1921 were investigated by Milne [1922, 1924]. In some respects it is unfortunate that these investigations

* A maund = 82 lbs. approx. 1 seer = 1/40th maund.

† Peasant farmer.

did not start until after the "failure" had been established. They contain however extremely valuable information, which will be discussed later in its due place.

The 1926 and 1928 failures came within my own experience. Systematic records throughout the seasons 1926 to 1929 are available, and the history of the crop prior to the failure can be traced.

Symptoms of the Failure.

The failures are frequently referred to as "the blight" or "the disease" of Punjab-American cotton. The terms denote those manifestations which accompany the marked reductions in yields in failure years, and which were described by Milne [1922, 1924]. These symptoms were that, after the 15th September, the 4F cotton plants shed their flowers and young bolls, the first pickings were very poor and late, the bolls did not open properly, the lint was trash,* the seed improperly developed, and the leaves turned yellow and red and eventually were shed. He also mentions in both reports that in July the plants were undersized, though in July 1919 the crop looked "fairly well".

Another symptom has now been noticed, which is that many of the young bolls at the end of August and beginning of September, when squeezed between the finger and thumb, are soft, and easily indented, whereas healthy bolls are almost stone hard. The soft bolls if opened, have a pulpy appearance, easily differentiated from the appearance of healthy bolls.

To test the validity of this symptom, a number of hard and soft bolls were labelled, and the type of opening recorded. This information is given below in Table II, and shows that the bolls which were hard at the time of labelling produced a much larger percentage of properly opened bolls. The seed weight, the lint weight per boll, and the *kapas* per boll also rise steadily from the soft bolls to hard bolls, showing that the hard bolls received more nutrient material than the soft bolls. The year 1928 was a failure year; and there were many more soft bolls to be found than hard bolls; in 1929, when there was little bad opening, soft bolls were difficult to find. As the distinction between hard and soft is a personal one, and several individual members of my staff did the selection, the 1928 results are not absolutely clear-cut and some of the bolls recorded as hard eventually opened badly. The differences, nevertheless, are sufficiently large to show that an undue proportion of soft bolls may be taken as an indication of future bad opening.

The underdevelopment of the seed consists in the failure of the contained embryo to develop. The stage at which development is arrested varies from the

* In the "Technological Reports on Standard Indian Cottons, 1929", (Tech. Bull. Series A, No. 12, I.C.C.C. Tech. Lab. 1929, pp. 50-51), Dr. A. J. Turner shows what variations in the spinning capabilities of 4F were found in the cotton seasons 1924-28.

stage before the absorption of the endosperm, up to a perfect embryo, but one which does not fill the cavity of the seed completely, giving a shrivelled or wrinkled appearance, instead of the normal plumpness of the mature seed. Generally the testa is fully developed, and has become its normal black colour, but in bad failures, the black testa colour may remain undeveloped in fully 50 per cent. of the seed.

Another and earlier appearance is a mottling of the leaves, giving a mosaic effect, and in 1926, the leaves were universally covered with brown angular spots, and stems and branches had blackish lesions. This gave rise to the suspicion of a *B. malvacearum* attack, but as these symptoms were not particularly noticeable in 1928, and only saprophytic fungi were found on the leaves by the Imperial Mycologist in 1926, they cannot be definitely called *symptoms* of the 'disease'. It seems more likely now that the plant had already been rendered susceptible to disease and in the hot humid conditions of July and August, fungi were able to develop freely, and took advantage of insect punctures in the leaf to take on a parasitic mode of life.

Another, and what may prove to be an important observation, was made in 1926 when it was discovered that non-dehiscence of the anthers of the fully formed flower was of frequent occurrence, and in the early part of the flowering period was 100 per cent. of the flower opening. This has been reported elsewhere [Trought 1928]. It has been found that the commencement of anther dehiscence varies from year to year, being later in 1926 and 1928 than in 1927 and 1929. This phenomenon will be referred to later, but it may be mentioned here that the failure to develop its pollen grains properly by the plant may be related to the subsequent failure to develop its seeds properly, and may be considered as an index of the general health of the plant, and its liability to fail later in the season.

An interesting comparison of the symptoms of the failures in the Punjab may be made with those recorded by Johnson [1926, 1] for Rust, Yellow Leaf Blight, or Potash Hunger, and for Mosaic disease or Yellow Leaf Blight or Black Rust [1926, 2]. Brown [1927] and Collings [1926] combine Rust and Black Rust with Mosaic disease and Yellow Leaf Blight under one heading. The causes of the "disease" (or diseases) are given by Brown as :–

1. Lack of humus or vegetable matter in the soil.
2. Lack of potash.
3. Improper drainage.

Brown also remarks, rather significantly, that "Continuous cropping to corn and cotton without keeping up the supply of organic matter in the soil has put many fields in such a condition that cotton rusts badly. Rust also frequently develops on only the low lands of a field or only after a period of continued heavy

rain". In the light of what will appear later these remarks are of considerable interest.

It appears that an unhealty condition of the plant, brought about by soil conditions, increases the plant's susceptibility to " blight " in America. The same phenomenon also occurs in the Punjab. For example, Dr. Johnstone, quoted by Powell [1868] calls attention to the greater liability of (*desi*) cotton on hard compact land to aphis attack; and Milne, in his reports, emphasised the different degrees of " failure " to be found in (American) cotton grown on different soil types. Soil condition however is not an *originating cause* of the annual fluctuations in yield (see next paragraph), though it may be one of the determining factors in any particular field between failure and non-failure.

Possible Causes of Failure.

It should be particularly noted that in certain years, such as 1924, and 1925, the 4F crop was extremely good. This fact alone is sufficient to dispose of the popular fallacy that there had been any serious deterioration of type. It is impossible to ascribe the failure of 1921 to seed deterioration when 4 years later,

TABLE II.

Observations made on 'Soft', 'Medium' and 'Hard' bolls after dehiscence.

	No. of bolls labelled	Well opened bolls	Mediumly opened bolls	Badly opened bolls	Wt. of seed cotton per boll in grams	Wt. of seed per boll in grams	Wt. of lint per boll in grams	Wt. of 100 seeds in grams	Lint index	G. O. T.
		Per cent.	Per cent.	Per cent.						Per cent.
Soft Bolls .	29	32·3	12·9	54·8	1·51	1·04	0·46	6·2	2·8	30·6
Medium Bolls	35	65·7	8·6	25·7	1·96	1·35	0·61	6·5	2·9	31·1
Hard Bolls .	38	78·9	13·2	7·9	2·49	1·66	0·82	7·6	3·7	33·0

NOTE.—Bolls were selected and labelled by four different observers.

in 1925, the same type gave 16 maunds per acre (see Table I). Furthermore, examination of 100 bolls collected at random from a commercial crop of 4F in 1925 showed that it was of considerable uniformity for a commercial crop. In Egypt new varieties were supposed, prior to Balls' era, to have a life of only 10 to 15 years. Balls [1919] pointed out that with adequate precautions a variety can

be maintained unchanged for any length of time and the history of Domains Sakel seed has borne this out [Anon, 1922]. Kearney [1922] also confirms this in the case of Pima Cotton. One of the undoubted reasons for the uniformity of 4F, after it had been in general cultivation for a number of years, is that in many districts 4F comprised practically the whole of the American cotton crop of the district and that, in this respect, the Punjab was almost a "One Variety Community". It is now a commonplace that, although there may be a mixture at the gins of *desi* and American types resulting in a mixed crop in the field, no natural hybridisation can take place *in the field* between these two types, so that this mixing in the gin could not affect the purity of the 4F, so long as 4F was the only American type grown.*

From an examination of Table I in the introductory paragraph, and bearing in mind the high standard of cultivation employed on the two farms mentioned, one definite conclusion is permissible, that the general fluctuations in yield cannot be ascribed to soil, cultivation or seasonal variations in water-supply. Each of these factors will naturally affect the actual yields obtained on any particular plot; bad soil, bad cultivation or bad water-supply will obviously lower, comparatively, the yields per acre, just as an improvement in the general standard of cultivation by the ordinary small *zemindar* would be expected to increase average yields per acre. The annual fluctuations would not be eliminated thereby, though a profitable, as opposed to an unprofitable crop might be obtained, even in bad years.†

An obvious possibility, accounting for seasonal fluctuations, would be looked for in the differential incidence from year to year of diseases or pests. This will be considered in the next section. Succeeding sections will then deal with the effects of different environmental and climatic factors on the crop, and physiological factors, such as bud-shedding, non-dehiscence of anthers, boll-competition and root development will be considered in some detail.

Diseases and Pests.

So far as fungus and bacterial diseases are concerned there are no records of any such disease having caused widespread havoc in the Punjab, sufficient to account for a considerable decrease in yield such as may occur with *Bacterium malvacearum* (Black Arm) in the Sudan, some of the boll rots in the West Indies, or the Texas Root Rot and Angular Leaf Spot in the U. S. A.

* When new types of American cotton are introduced to compete with 4 F, this mixture at the gins will constitute a serious menace to the purity of the American crop, and unless measures are taken to prevent mixing, and to control seed supply, by a suitable seed distribution scheme, and controlled ginning in the early stages, the deterioration of new types will proceed apace.

† The results obtained in rotation experiments on the Lyallpur Agricultural Station (*vide* the Annual Reports of the Department of Agriculture, Punjab, in recent years) show that it is possible, under conditions of intensive farming, to obtain paying yields of cotton in bad years.

With insect pests, the case is different.

In 1868 Baden H. Powell [1868] gave a brief account, quoting from Dr. Johnstone, of the diseases and pests of cotton in the Punjab. Although there was American cotton in cultivation at this time, it must be assumed that the bulk of the crop was of the *desi* type.

The one which is of most interest at the present day is the one he calls "*Thela*", so called because of the oily exudation on the leaves. Although the description of the parasite as "*Aphis lanigera*" is very circumstantial, it seems possible that here we have the first record of the "White fly" (*Bemsia gossypipe.da*, Misra and Lamba). Mr. Afzal Husain, Entomologist to Government, Punjab, to whom this question was referred thinks it possible that the blight might have been due to "Jassid" attack.

The present most serious pests are the Spotted Boll Worm, the Pink Boll Worm, the White Fly and the Jassid. It is clear that the uneven incidence of insect attack might account for considerable variations in outturn. For example, the year 1905 was a bad "boll-worm year" [Lefroy, 1909]. Lefroy here reports that the cotton was also attacked by "Cotton aphis (*tela*)". He visited the affected area early in November, 1905, and ascribed the failure to *Earias* boll-worm, which were present in enormous numbers. He says the cotton had been "weakened by want of rain and by the ravages of Aphis". Here there is the opinion implied that a weakened plant is more liable to insect attack (*vide infra*). Lefroy says that actual aphids were seen in November, otherwise it might have been suggested that the reported aphis attack was actually White Fly. Before the present spread of knowledge about the White Fly, the Aphis and White Fly were undoubtedly confused by untrained observers, and many records of Aphis attack referred to the White Fly. The year 1911 was also a boll-worm year [Milne, 1922], and in 1913 Jassids did considerable damage to smooth-leaved American types. The general cultivation of hairy-leaved types has, however, done much to decrease the likelihood of damage from Jassids. On the other hand, in 1919 and 1921 failures, Milne (*loc. cit*) reports that *Earias* boll-worm did not cause the failure, and that there was no other insect or fungal disease to which the failure could be attributed.

Recently the belief has been gaining ground that an insect epidemic on a crop is, in the first place, due to a weakness of the plant, which may have been brought about by poor cultivation, inadequate manuring, poor water-supply or an exceptionally stringent set of environmental conditions.

Howard [1921, 1924], Andrews † [1923], Lees [1926], Mumford [1926], Turner [1929] and Davidson and Henson [1929] are among the authors who have pointed

† I am indebted to Captain Prideaux, Oat Hay Farm, Okara, for a very full extract of this paper, which I have not seen myself in original. T. T.

out that the incidence of insect attack may depend on the internal condition of the plant, which itself depends very largely on the physiological response of the crop to its environment. The insects particularly referred to are suctorial insects which feed on the leaf or stem sap. Naturally an insect attack such as is caused by a flight of locusts, which does not depend on the condition of the plant, though it may be equally destructive, cannot be considered in this connection. We have however already seen that, in the Punjab, poor cultivation and insufficient water are not the primary factors influencing yield variations. If insect attacks however should be the main cause of variations in yield then on the theory enunciated above, we should be thrown back on the climatic or environmental conditions which induce in the plant such a condition as to enable an insect attack to become devastating. Mumford's paper [1926] is of very considerable interest in this connection, as it deals with pests of the cotton plant.

A study of those conditions which effect the plant itself would thus be necessary before any primary control measures for the pest could be suggested.

A theory has been advanced by Mr. Roger Thomas [Roberts, 1929] that White Fly is the sole cause of those decreased yields of cotton, which in 1919, 1921, 1926 and 1928 and to a less degree in 1927, were of such magnitude as to cause a very serious, if not crippling, loss to cotton growers, and an equally serious loss to the Punjab Government on account of the consequent loss of revenue by remissions.

It is during July and August that the attack of White Fly (and also Jassid) is liable to be serious, and it is certain that in some years White Fly can develop into a major pest.

Provided the plant is susceptible—and it will be shown in the review of the effects of climate on the plant that there are many causes which may induce such a condition in the plant—the warm humidity of these months combined with ample food supply, would appear to be favourable to the rapid multiplication of the pest.

The reason why these insects are not equally destructive from season to season seems clear from the botanical point of view, namely, that in one season owing to less unfavourable conditions during the early part of the season the plant is less adapted to act as a host plant, than in another. Andrews [1923] observed that the Tea Mosquito Bug appeared to find tea bushes, to which certain manurial constituents had been applied, definitely distasteful. A somewhat similar reaction has been reported by Davidson and Henson [1929] on the increased wandering propensity shown by the Bean Aphis on plants which had been dosed with Epsom salts. If the White Fly do not find the cotton plants to their liking, it may be confidently assumed, till experimental evidence to the contrary is produced, that their life-histories and reproduction on the cotton plant will be interfered with. The reaction to this state of affairs perhaps may be to render the White Fly more palatable to its

own predatory enemies (such as ladybird larvæ, etc.), with a further cumulative depressant effect on the White Fly; the "balance of nature" referred to frequently in entomological publications, depends here on the chemical composition of the cotton leaf sap. That the composition of leaf sap is a variable factor under different soil conditions, at different times in the season, and even at different times of the day has been shown by many workers, [Combes and Echevin, 1926], [Maskell, 1927], [Thomas, 1927], [Johnston and Dore, 1928], [Turner, 1929], [Wallace, 1928-29], etc.

Apart, however, from the condition of the plant, and from such biological control as may occur, rainfall is also considered to be an important factor in keeping the ravages of White Fly in check. Showers of rain undoubtedly would have a beneficial effect in destroying the fly, as well as in assisting the plant to resist attack. In August 1929, from the 20th to 28th there were a number of sharp showers, and afterwards, at Lyallpur, the attack of White Fly, which was serious prior to these rains, became negligible. It seems that short sharp showers at frequent intervals are likely to have a more destructive effect than heavier rains at longer intervals. Lefroy [1909] commenting on the beneficial effect of rainfall, thinks, however, that other causes and not rainfall may determine the decrease in attack which is generally noticed after a shower.

The effect of innumerable suctorial insects on the leaves, removing the plant sap, need not be stressed. The reduction in translocatory food material must react unfavourably on the growth of roots, shoots and reproductive organs. Further, the punctures caused by the insect may permit of the entrance and growth of the fungus *Rhizopus nigricans*, which has been shown by Briton-Jones [1923] to be a potential parasite on cotton bolls in Egypt, and which is very frequently associated with a serious attack of White Fly; also the honeydew excreted by the insects may block the stomata, and interfere with assimilation.

It will be seen that White Fly can be an extremely serious pest, as it aggravates all the evils of malnutrition from which the plant is liable to suffer, and in the event of a severe or prolonged attack may destroy the crop.*

* Postscript:—M. Afzal Husain, in "A Preliminary Note on the White Fly of Cottons in the Punjab" [1930] has examined this question of White Fly attack from the entomological standpoint. He considers the White Fly as a serious pest of cottons, but says under reservation "it is highly doubtful if it is the main cause of the widespread failure of the cotton crop". He thinks the White Fly lowers the vitality of the plant, but does not refer to those views quoted above that a lowered vitality in the plant may account, in the first place, for an increased incidence of attack by the pest. His evidence that the White Fly reduces yield through non-formation and dropping of bolls is interesting as lending support to the suggestion on page 330 that a White Fly attack might save the crop, through the reduction of boll competition.

Review of Climatic and Physiological Factors.

It is a difficult matter to attempt to separate the effects of the different factors of a climatic complex, as each factor interacts with other factors. The climate during the cotton season from May to October can however be divided roughly into three seasons—

(*a*) the very hot and dry months of May and June,
(*b*) the hot and damp months of July and August, and
(*c*) the warm, but with cooler nights, and generally damp climate of September and October.

As a 'failure' is established by the time of boll opening in October these three periods only will be considered. These periods also agree in the main with three periods of the crop's development, namely :—

(1) the early stage,
(2) the stage of rapid vegetative growth, and flower-bud development, and
(3) the stage of flowering and boll development.

As far as may be, therefore, the different climatic factors concerned will be reviewed in relation to these three stages of the crop, but in addition it has been found more convenient to include details of the physiological reactions of the plant under the appropriate sections, thereby obtaining a clearer picture of the plant's relationship to its environment.

In dealing however with such a variable as "climate" no such examination can be completely exhaustive, nor has it been found possible to use any one particular factor or combination of factors as a definite index of the plant's development.

(1) The Early Stages of the Crop's Development.

The general sowing date of the 4F American Cotton crop may be taken as from the beginning to the middle of May. The recent tendency to later sowing has not yet become general but will be referred to.

(*a*) *Air Temperature.*

The maximum air temperatures during May and June are high. A comparison has been made [Trought, 1931] of the maximum air temperatures at Lahore* with temperatures as given by C. B. Williams for other cotton growing countries at the time of sowing, and during the early development of the crop. The comparison is

* Lahore temperatures were taken as they have been published by the Meteorological Department of the Government of India. They may be considered as intermediate between the somewhat higher temperatures of the irrigated areas of the S. W. Punjab, and the rather lower temperatures of Lyallpur.

sufficient to show the abnormally high temperatures which prevail. The effect of such temperatures on germination and early development must be considerable, more particularly in their relation to other factors. The internal temperatures of the leaves follow closely the temperature of the surrounding air*, and as the formation of carbohydrates falls away rapidly after a temperature of 38°C. is reached, there is a consequent reduction from the optimum rate of assimilation.

Evaporation from the surface of the soil increases with rise in temperature, and transpiration from the leaves—even if there were no corresponding reduction in relative humidity correlated with increased temperature—becomes abnormally rapid at these high temperatures.

(*b*) *Relative Humidity.*

Relative humidity during May and June is low, and augments also the comparative rapidity of evaporation from the soil and transpiration from the leaves. The more rapid transpiration lessens leaf turgidity, and leaves actually become flaccid during the middle of the day. Stomatal closure consequent on this water loss is hastened, with a consequent reduction in assimilation. The small size of the plants means that little or no check is exercised on soil evaporation by shading or interference with air movement, and the upper layers of the soil, which at this early stage of the plants' growth contain a majority of the roots, suffer severely from desiccation. [Soil moisture determinations show that during this period there is a much more rapid loss from the first foot of soil than from lower depths, and the root-washing experiments show that in a bad year such as 1928, the roots had not penetrated more than one foot (30 cms.) at 7 weeks old.]

Growth in length has been shown to depend to a very considerable extent on the residual availability to the plant of soil moisture, after the demands of transpiration have been satisfied. The average heights recorded in beds receiving different types of watering in 1928 are as under :—

Watered on	Height on 5th June 1928	Height on 2nd August 1928
22nd May, 12th June, 3rd July . .	1′9″	3′5″
29th May, 26th June	1′7″	3′5″
5th June, 10th July	1′4″	3′3″

There was 3·0″ rain on 24th July.

The figures show that the delay in watering of a week or a fortnight in the early stages has an effect on growth in height, and that the effect may be continued into August, but it is interesting to note that the plant was able to recover where watering was only delayed a week.

* This has been shown to be true by several authors for plants other than cotton ; and unpublished figures for cotton obtained by Rai Sahib Jai Chand Luthra, Associate Professor of Botany, Lyallpur, confirm this fact for cotton.

The combination of high maximum air temperatures and low atmospheric humidities during the early stages would naturally be expected to be detrimental to the crop's development when they occur. Milne, for example, records that in 1919 the season was very hot and dry till July 20th, and in 1921 also the early part of the season was excessively hot and dry, and that there was little rain the previous winter, giving the probability of insufficient soil moisture being stored in the soil. In 1925, a good year, maximum air temperatures were relatively low, and humidities high. On the other hand, in 1926, a bad year, temperatures were abnormally low until nearly the end of June, and humidities higher than would be expected for May, though June was dry.

Extremes of temperature and humidity during these months, cannot be said, therefore, to be the sole cause of failure.

(*c*) *Soil Temperatures.*

Camp and Walker's [1927] work with cotton seedlings shows that when the soil is maintained at a higher temperature than about 34°C., germination is somewhat delayed, and early growth reduced. Even allowing for the temporary lowering of soil temperature, due to the irrigation prior to sowing, an examination of the diagram (Diag. II) shows that in May the maximum soil temperatures at 5 cms. depth in the cotton field are much above the optimum temperature found by these workers; and though these maximum temperatures are not maintained throughout the 24 hours, it seems they must exercise an unfavourable effect, giving the plant a bad start from the beginning.

An additional effect of high soil temperature influencing assimilation, and reducing it from its optimum, may be found in the partial sterilization of the upper layers of the soil during these months. Diag. II shows the weekly average maxima of soil temperatures at 5 cms. depth. The suppression so induced of bacteriological and also protozoan activity results in a lessened evolution of CO_2 from the soil. This is also aggravated by the usually low humus content of Punjab soils. An increase of CO_2 content in the crop's atmosphere would result in increased photosynthesis. Spoehr [1926] referring to experiments by Leather, Lundegardh, etc., says that "it is apparent that the production of carbon dioxide by the soil may exert a decided influence on the development of plants".

(*d*) *Insolation.*

May and June are months when the sun's effect is very powerful. Priestley [1929] calls attention to the destructive effect of strong light on chlorophyll and to the loss of chlorophyll which occurs when light is too strong or too long continued.

He also refers to the effect of sugar accumulation in the leaf in retarding photosynthetic activity. Brenchley [1920], working with peas, expresses the opinion that beyond a certain limit, the beneficial factors of heat and bright sunshine become harmful and result in the premature death of the plant. The degree of chlorophyll concentration in the leaf affects the rate of growth [compare the results of Sprague and Shive (1929) with maize]. From year to year, as shown in Diagram III, there are quite considerable differences in the hours of sunshine, and it is legitimate to assume therefore that any harmful effect of excessive insolation would also vary from year to year and may have a definitely deleterious result on the plant's development. It is interesting to note in Diagram III that during May 1928 (a failure year) the hours of sunshine reached a very high level.

The work of Schertz [1929] however is also of interest in this connection. He shows that the chlorophyll content of cotton leaves can vary within fairly wide limits without any apparent direct effect on final yield ; and that though in general, highest yields of cotton are obtained through nitrogen manuring, which results in higher chlorophyll content of the leaf, this does not obtain in the case of potatoes, where high nitrogen manuring resulted in high chlorophyll content of the leaf but a decreased yield of tubers. The difference in the behaviour of the two crops would account for this, but his results support the suggestion that with cotton at least a diminution in chlorophyll content of the leaf is harmful.

(*e*) *Dust-storms.*

The depressant effect of dust-storms on growth has been recorded elsewhere [Trought, 1931]. The great majority of dust-storms occur during May and June, so the figures may be conveniently considered here.

The records show that from May to October in 1919, 1921, 1926 and 1928 there were 32, 42, 33 and 40 dust-storms, while in 1924, 1925, 1927 and 1929 there were 22, 28, 29 and 37 dust-storms*. (In totalling these figures a day on which a dust-haze was recorded was arbitrarily considered as " half a dust-storm ".)

It must not be forgotton that dust-storms are generally very local phenomena, and though it may be that general conditions which give rise to frequent dust-storms are adverse to the cotton crop's growth, undue weight should not be given to these figures.

(2) The Period of Vegetative Growth and Flower Bud Formation.

In July and August the conditions are obviously favourable for vegetative growth. When shoot growth is rapid, root growth, provided equally favourable

* 20 of these dust-storms were recorded as 40 dust-hazes. My meteorological observer however only recorded twelve dust-storms in this year, as against seventeen recorded by the official meteorological observer. In the recording of dust-storms and dust-hazes there is obviously no exact criterion which can be taken to distinguish them.

conditions prevail for root growth, should be equally rapid. But it will be shown that conditions may occur during this period which are unfavourable for root growth. There may also be competition between shoot and root for nutrient material, and the division between the root and shoot of the limited material available may not be evenly balanced. There may be a differential partition in favour of the shoot. If shoot growth is too rapid, this may definitely restrict root growth, as noted by Lees [1926] in the case of apple and strawberry.

Shoot growth practically ceases at the end of August, and this cessation can be correlated with the development of the bolls. There is undoubtedly a movement of nutrients to the bolls rather than to the growing points of the shoot at this stage.

The rise of the flowering curve starts from the 15th to 20th August ; records in 1928 show a 33 day period, and in 1929 a 35 day period for the maturation of the bud to the flower. Flower-bud production may thus be considered as commencing from the middle of July.

(*a*) *Air Temperature.*

The air temperatures are still high at the beginning of July, but fall rapidly. An examination of the curves leads to the conclusion that during this stage air temperatures are unlikely to be of such a magnitude as to cause unfavourable reactions in the plant. The range of temperatures from one season to another is not great ; and there is no suggestion that in any particular year temperatures are likely to exert any definite depressant effect on plant growth.

(*b*) *Humidity.*

With the approach of the monsoon, the general atmospheric humidity of the Punjab increases. This effect does not appear to depend on the actual rainfall recorded at any particular place, as is shown by the comparison in Table IV of the 8-0 A. M. humidities at Dera Ismail Khan, Lyallpur and Lahore for June, July and August. The isohyetal lines given by Milne [1922] show that these places have a normal of 7″, 10″ and 20″ of rainfall, respectively. The figures in the table show no definite relation between the atmospheric humidity and normal rainfall at these places, but do show that there is from the beginning of June a definite and general increased humidity over a large area, which is the result of what is known as " the extension of the monsoon ". The humidities at Lyallpur for the four years 1926-29 (Diagram IV) show clearly that the general trend of atmospheric humidity is a rising one from mid-June, and this is confirmed by the evaporation data (Diagram V).

(c) Rainfall and Water-logging.

In the earlier stage of growth rains occur, but at infrequent intervals, and are followed by an increased rate of elongation. During this second stage of growth, there is the general expectation of rain at more frequent intervals, and it is not invariable that rainfall should be followed by an increased growth rate. The growth curves show that during July and August there are checks to growth quite frequently, and that these checks can at times be attributed to that type of physiological drought which is caused by over-watering. A good example was seen in 1926 when over 3 inches of rain on successive days (13th and 14th July) was followed by a rapid drop in growth [Trought, 1931].

Cannon [1925] also found that flooding decreased greatly the rate of growth of the main root of cotton. This flooding effect would be made more serious by the fact that in the Punjab the soil type is generally alluvial, and the soil is liable to become puddled and sodden with the sharp heavy showers which characterise the rainfall when it does come. The upper surface* of the soil after one of these showers is almost impermeable to water, and in consequence the water stands on the soil surface, until the combined efforts of evaporation and what slight percolation there may be, remove it. The effect of evaporation is, at this time, decreased owing to the larger size of the plants and their shading effect on the soil, and in consequence the waterlogging effect may be prolonged sufficiently to be harmful. The preliminary work of Singh [1922] is of interest here. He showed that when wheat, growing in pots in heavy soil, was watered from above, there was a marked decrease in the dry weight of the roots produced as compared with the dry weight of the roots of plants grown in the same soil, but watered from below.

Table VII includes data obtained from root washing experiments with cotton done in 1929 at Lyallpur, and which show that after shoot growth is finished there is a development of root growth.

In 1928 however the records on root development showed that after August, root growth not only failed to make any headway, but actually there was a dying off of the deeper roots. This "root destruction" was due to abnormally heavy falls of rain in the last days of August and on 1st September which caused widespread floods and serious water-logging of the soil, with consequent ill effects on root development. This is a somewhat extreme and unusual case, but from it, it will readily be realised that rainfall during the course of the growth of the plant can affect root growth adversely in so much as it may cause water-logging, reducing the soil

* This formation of an impermeable layer is seen repeatedly during the summer on fallow land which has not received any cultivation. The depth of penetration is limited to the surface skin. A similar phenomenon is seen in the thick dust on the roads in summer, the rain does not penetrate beyond the surface layer of dust, which then dries out into a crust.

aeration, with a consequent reduction in root absorption, and a lessened supply of nutrients to the plant.

The soil conditions caused by flooding and heavy showers will also affect to some extent the development of bacteria, with a decreased supply of available nitrogen for the plant.

(*d*) *Bud-formation and Bud-shedding.*

It is at this stage, when buds are being formed and developing that according to Kudrin [1929] the cotton plant requires most mineral nutrients. On the other hand, Fraps [1919] shows that the final yield of cotton is not in direct proportion to the amount of mineral salts taken up by the plant from the soil. But any interference at this stage with normal absorption of nutrient would naturally be detrimental to the plant and render its internal condition more susceptible to insect attack, or less resistant to later unfavourable conditions.

One method by which the plant attempts to adjust itself to the conditions is by the shedding of buds. Bud-shedding is heavy during July and August. At the same time bud-production is rapid, and from the middle of July an increasing number of buds are destined to complete their development and open into flowers. This development of the flowers requires, according to Kudrin, an increased supply of nitrogen and ash constituents, and results in a migration of these constituents from the vegetative to the generative organs. From the middle of July (when bud-formation attains importance), there is thus an increased drain on the available food supply.

Records made in another connection are also of interest. Table V gives the results of observations made on the maturation of the developing bud to the flowering stage. A number of buds were labelled weekly at the stage when they were just visible at the growing point. The number of buds which were shed was recorded and the dates of flower-opening of the remaining buds noted. From the table, it will be seen that there were very considerable differences in the percentages of buds which matured from week to week. In 1928 there was complete shedding as late as the 13th August with the variety 289F, whereas in 1929 over a third of the buds labelled on the 26th of July matured. With the 4F variety this difference is not so striking, but in 1928 4F opened badly, whereas in 1929 it opened well. The 289F in both years opened well. This difference in boll-opening can be accounted for by the difference in behaviour shown by the two varieties in the two years. In the 289F in 1928, owing to bud-shedding, the plant relieved itself of the strain of flower and boll-production until more favourable conditions supervened, with the result that the opening when it did come was satisfactory. 4F on the other hand produced flowers from the more early developed buds which, due, to non-dehiscence

of their anthers (see next section), were all shed. It thereby wasted its effort and was unable to produce properly opened bolls from those flowers which set bolls later, after anther dehiscence had occurred. In 1929 on the other hand, anther dehiscence occurred earlier so that the earlier produced flowers were able to set their bolls, the plant then decreased bud-formation and increased its bud-shedding, so decreasing the competition for nutrient to the developing boll, with the consequence that better boll-development was attained.

A similar phenomenon is seen in the Mollisoni* records for the two years. It is obvious that during July and early August in 1928, the conditions were much more unfavourable for Mollisoni than in 1929. The 1929 records for Mollisoni compared with those for 4F and 289F of same year give the presumption that Mollisoni, as would be expected, is a hardier cotton than the two American varieties. The figures for the Early Strain in 1929 when compared with Mollisoni are interesting in this connection owing to their similarity. The plants of the Early Strain were on the whole very wide-spaced and were therefore more capable of supplying sufficient nutrients for boll-development. Apart from this, it is also believed that the Early Strain is more resistant than 4F to unfavourable climatic conditions. This strain however also shows an increased bud-shedding which occurs as a consequence of the setting of fruit from the earlier opened flowers.

Another interesting fact brought out by this table is that during July for both 289F and 4F the maturation from bud to flower shows in both years an increased period as compared with that for the later formed buds. The hardier Mollisoni does not show this nor does the wide-spaced Early Strain. A deduction from this, that the two American types found more difficulty in providing the developing flower buds with the necessary mineral constituents and that thus the development period was lengthened, appears to be justified.

(e) *Non-dehiscence of anthers.*

A consequeuce of the inhibited development of the plant can be seen in the non-dehiscence of anthers. This phenomenon has been described earlier [Trought, 1928]. The pollen grains remain undeveloped, and no fertilisation of the flower which is otherwise fully formed, takes place. The flowers all shed within two or three days, and a stimulus is thus given to the plant to produce more flower buds, as proved experimentally by Ewing [1918] and Eaton [1927]. There is a resultant waste of nutrient material, for instead of nutrient material being used for the development of bolls, it is used for a further production of flower buds.

It has been found that the percentage dehiscence of anthers increases towards the end of August, but that it varies from season to season, also that full dehiscence

* *G. indicum* var. *Mollisoni* of Gammie.

was attained later in those seasons which eventually proved to be bad, such as 1926 and 1928, than in those in which boll-opening was good such as 1929, and was intermediate in 1927, a medium year. It is suggested that a prolongation of unfavourable factors shows itself first in a prolongation of the period of non-dehiscence and later in improperly developed seed and bolls. As shown by Milne [1922, 1924] there are quite considerable variations from field to field in the severity of the " disease ". It is found that anther dehiscence also varies in intensity according to locality or variety, a condition which would be expected if the differences can be attributed to local variations of food supply and soil conditions ; but it is also found, that though local differences in amplitude occur, the general major fluctuations of the percentage dehiscence curves run together. This condition would be expected if these major fluctuations were determined by more generally operative factors. So far it has not been found possible to correlate in any way the major or minor fluctuations with any one climatic factor. It was thought, for example, that non-dehiscence in 1927 might have some connection with soil temperatures or with growth in height, but in 1928 the records showed absolutely no connection in these two respects.

(3) The Stage of Flowering and Boll-development.

This stage in the crop's development comprises the months of September and October. During September flowering reaches its maximum, boll setting occurs, and in normal years the bolls begin to open about the middle of October. Growth in height ceases with the rise of the flowering curve, and flowering in its turn ceases with the opening of the bolls (Diags. VI and VII). It is at this time the plant is supposed to make the greatest demands for water. McClelland [1918] for example gives the blooming and fruiting time as the time when the cotton plant uses most water.

Milne also in his reports [1922, 1924] has considered carefully the conditions prevailing during this period. He concludes that the cause of the failures in both 1919 and 1921 was due to an insufficient supply of moisture in the soil during September and October at a time when the plants are producing the greater part of their flowers and fruits, *i.e.*, when there is the greatest demand made by the plant for water.

The climatic factors in operation during this stage are much less severe than during either of the earlier stages. The plant is well-grown, and from that cause alone, due to the shading of the soil, the shading of the majority of the leaves from direct insolation and the checking of air movement within the crop, it is better able to cope with any environmental severity which may occur.

Climatic factors will be dealt with therefore more briefly, and as a whole. In general September and October would be described as " good growing weather ".

(a) *Climatic factors during the third stage of development.*

Diagrams I and VIII give the records of air-shade temperature. These show variations from year to year during September, around a mean of approximately 98°F., falling away at the end of October. In 1919, the temperatures were comparatively high, and in 1926 comparatively low. In 1925, the early part of September was hotter than usual, and in 1929 temperatures were medium. It is difficult to connect, therefore, the subsequent failures of 1919 and 1926, or the subsequent good opening of 1925 and 1929 with temperature during this period.

It is difficult, similarly, to find any connection with the humidities which occur, and the subsequent condition of the crop. Diagram V, giving evaporation *within* the crop shows quite clearly that the ' crop atmosphere ' is maintained at a very uniform level of humidity during September and October. The evaporation in 1926 and 1929 was very similar while the lowest evaporation is recorded for 1928 (a failure year). Insolation is uniformly high and there are few dust-storms.

The records at Lyallpur show that rainfall is unimportant in its effect on the crop—for example in 1929 little more than an inch of rain fell in September and October, while nearly 3 inches fell in the same two months in 1926. In some localities other than Lyallpur, in the American cotton-growing area, no rain would be expected. The variations in rainfall at different localities in different years can therefore have little, if any, relation to a general failure, though a timely rain, or—equally —an untimely or excessive rain, may cause a local variation in the degree of failure.

Balls [1913] calculated that in Egypt the greatest loss from transpiration was during July, when flowering and boll-setting are in progress. July corresponds, as regards the Egyptian crop with mid-August to mid-September in the Punjab. Comparing the Egyptian crop with the Punjab American crop, Balls' conclusion that the Egyptian crop transpires much more water than is put on in irrigation is also of interest. It gives rise to the speculation as to whether the 4F crop is, *in practice*, ever able to receive as much water as it requires. Watering experiments at Lyallpur show that an increase in the amount of water applied increases the yield, and in 1928 an abnormally high correlation coefficient (+·98) was obtained, while in 1929 the correlation coefficient was + ·90. These watering experiments were on a large scale. Ten repetitions of each type of watering were employed, and the amount of water put on to each plot at each irrigation was measured by means of a Cipoletti weir, and the readings reduced to inches of water per acre. Waterings were at three-weekly, four-weekly and five-weekly intervals after sowing, and different variations were introduced by shortening or lengthening the interval between waterings in the

later part of the season. Comparisons were also made between three, four and five-weekly intervals where cotton was sown on the flat and on the Egyptian type of ridge. A typical *zemindari* watering was introduced as a standard. In arranging waterings during the rainy season arbitrary allowances had to be made for rainfall. The differences in rainfall do not permit of the experiments being absolutely uniform from season to season, and are one of the difficulties of irrigation experiments with cotton at Lyallpur.

In 1927 in addition to comparing 'ridged' *versus* 'flat', a series of beds with shoot pruning was also tried. The yields of *kapas* per acre in this year were small however, probably due to poor soil, and it is doubtful whether the results are of much value. The standard error was 30 per cent. of the mean, and the coefficient of variation 42 per cent. In 1928 and 1929, the standard errors were 13·2 per cent. and 7·2 per cent. of the mean, respectively, and the coefficients of variation 25·8 and 21·3 respectively. These results are therefore much more reliable.

(b) *Soil Moisture.*

Soil moisture determinations were done in conjunction with these watering experiments by the Agricultural Chemist to Government, Punjab, in 1928 and 1929. In both years they show that there was a rapid loss of water from the soil during September. The figures given in Table VI have been calculated from the percentage moisture determinations. The figures for loss per day in the final column show some disparity from the average figure of approximately 21 tons per day due to transpiration alone given by Balls and Holton [1915]. The disparity is accounted for by the fact that 4F is a much hairier cotton than the Egyptian plant, and so presumably transpires less ; and also during the season when the plant has obtained its full size, and actual water loss through the plant is at its maximum, the atmospheric humidity is, on the average, probably higher in the Punjab than in Egypt, thereby further reducing the loss by transpiration. The normal relative humidity given for Giza,* is given as " Mean of Day ", whereas the 8·0 A.M. relative humidities only are available for the Punjab, so no comparative figures are available. The above is a personal opinion based on residence in both localities.†

* Climatological Normals for Egypt and the Sudan, etc., Government Press, Cairo, 1922.

† The following figures have become available, which as far as they go endorse my opinion. From the point of view of the crop's development, June, July and August in Egypt compare approximately with July, August and September at Lyallpur.

	May	June	July	August	September
Normal relative humidity at Giza (mean of day).	55 per cent.	56 per cent.	61 per cent.	67 per cent.	73 per cent.
1929 Relative humidity at Lyallpur (Mean of day).	32 ,,	37 ,,	63 ,,	76·5 ,,	72·5 ,,

(c) *Flowering Curves.*

It will be noted that from year to year there are rather remarkable differences in the flowering curves (Diag. VI). When these differences are considered together with the differences in time of anther dehiscence from year to year, it is clear that each year the plant makes a different demand on the root-system for flower and boll production. The dates of anther dehiscence are shown on the diagram. In 1926, for example, there is an early rise of flowering with late anther dehiscence and as shown in the curve this is followed by a second rapid rise of flowering. This is the consequence of the stimulus to increased flower production given by early and complete flower shedding. In 1929, where anther dehiscence was earlier, the flowering curve rises much more gently, and there is actually a considerably less total number of flowers produced than in 1926, which was a failure year. In 1928 at the time of anther dehiscence flowering had reached about one flower per plant per day. The early shedding of flowers in this year is reflected in the flowering curve later, and again a greater total of flowers are produced than in 1929. This variation in the number of flowers produced means also variation in the number of bolls which are developed. In different years there is a variation in the competition between boll and boll for available nutrients.

(*d*) *Boll-Shedding.*

This competition must play an important part in the final development of each individual boll. It has been found that a boll over 10 days old is very much less liable to shed than bolls which are less than 10 days old. This agrees with Egyptian experience where it is found that practically all the bolls were shed between the ages of 2 and 8 days [Bailey and Trought, 1927]. If, then, as in 1928, there is a rapid rate of flower production reached before boll setting commences, it means that actual boll setting when it does start is greater than would be normally expected. These bolls all being young bolls do not make as big a demand on a root-system as when they become older, and it thus happens that the shedding due to competition is reduced. However, when the bolls do become older they have reached that stage when their shedding is difficult or no longer possible and competition for nutrients becomes acute. As it is too late at this stage to relieve the strain entirely, bad opening occurs later. When the boll-setting occurs more gradually, the plant has a better opportunity of shedding the later formed bolls, which are still in the young stage.

The "catchnet" shedding records for the three years 1927, 1928 and 1929 provide some evidence in favour of these suggestions. In 1927 and 1928 when the plant was trying to restore normal conditions of nutrient supply bud and boll-shedd-

ing increased appreciably during September. In 1929, when owing to reduced flower production and early boll-setting, the competition was not so severe, there was little increase in boll or bud-shedding in September, and the total shedding was much less than in either of the previous two years. The figures given in Table VIII show the percentage distribution of shed bolls between different ages. In Table VIII are also shown the percentage of flowers which produced bolls in the years 1927, 1928, and 1929. These figures show the reality of this competition between bolls. In 1928, when the competition was more severe, as judged by final boll development, a much larger proportion of over 10 days old was shed than in 1929. In 1929, fewer flowers were produced, the competition was not so severe, and so a much greater proportion of the total flowers which opened, matured into bolls.

An increased boll-worm attack might have accounted for the greater boll-shedding of older bolls in 1928, but such increase as was recorded was small, and would not account for considerable differences in shedding. It is clearly possible, however, that a severe boll-worm attack following conditions leading to too great competition between bolls, might be able to cause sufficient shedding to allow proper development of the remaining bolls.*

(e) *Competition for nutrients.*

Between bud and boll.—At this stage also, when anther dehiscence has been late, the developing boll also has to compete with those buds which have been produced in response to the stimulus of " flower " shedding. The " catchnet " shedding records show an increased bud-shedding during September in 1927 and 1928, but not in 1929. The flowering curves are, nevertheless, still much higher in 1927 and 1928, than in 1929, and so, in spite of the increased shedding, there is still an increased competition of the bolls already produced with the developing flower buds and later young bolls.

Between boll and boll.—This competition between boll and boll is of considerable importance, and that it may operate on a field scale is shown by observations made in 1927 at Iqbalnagar in the Lower Bari Doab Colony. A plot of 4 F cotton on land which had just been taken into cultivation—a crop of turnips only had been taken after the land was broken up—showed complete bad opening. Every boll was affected, though the plants were well grown and bore plenty of bolls. In fact the most striking feature of the failure in 1927 in the Lower Bari Doab Colony was that the plants all bore a very large number of bolls but that every one of these bolls

*I believe that a somewhat similar paradox occurred in 1929, when the short-lived but severe White Fly attack induced early and almost complete flower bud shedding, with the result that the strain of flower production was greatly lessened, allowing earlier anther dehiscence and a more gradual production of young bolls. The plant was then able to get rid of any excess of bolls normally, by shedding in the young stage.

opens badly. The effect of boll competition was also shown in 1929, in a Pure Line family. One plant rather more wide-spaced than other plants bore over 100 bolls. The upper bolls of this plant opened badly, but on other plants in the same family bearing fewer bolls and at normal spacing there was no bad boll opening.

Possibility of actual shortage of nutrient supply.—That a shortage of nutrients may occur during this period was shown by investigations on the spot in *zemindars'* fields. On better soils, under conditions of good cultivation, or in other words, under circumstances presupposing a better nutrient supply, heavier crops were obtained than on worse soils and under worse conditions of cultivation. Competition amongst an excessive number of bolls for the available nutrients would thus aggravate any shortage. But it has been found also that the addition of nitrogen (as ammonium sulphate) at this time to the crop does not increase very much* the percentage of well-opened bolls but increases the total number of bolls produced and, therefore, the total number of good bolls produced. Its effect is to reduce shedding. The dressing of ammonium sulphate was not put on till rather late in the season (September 17th), and possibly a more complete artificial manure applied earlier would have increased the percentage of well opened bolls.

It should, however, be observed that this reduction in shedding, with increased nutrient supply, is not exactly the same thing as increasing the nutrient supply to the individual boll by a reduction in competition, though its final result—namely, increased yield—is the same. As boll opening in 1929 was good, although increased yields with late manuring were again obtained, no comparative figures of good and bad opening were obtained. In 1927 and 1928 a survey of the *zemindars'* crops showed that cotton after wheat did not do so well in general as cotton after fallow or *senji*† (see Table IX). This again points to there being a lack of nutrients available to the plant at this time of the season, and Brown's remark [1927] quoted earlier will be recalled. The table also gives point to the remarks made earlier that soil conditions, in themselves, cannot be entirely held accountable for " failures ", though less favourable soil conditions, such as would be induced by incomplete tillage after the wheat harvest, reduction in amount of plant food, etc., would tend to increase the incidence of malnutrition in the plant.

The reddening of the leaves referred to as one of the symptoms of the failure could be caused by nitrogen deficiency. Applications of nitrogen at this time do actually keep the leaves green longer than in control beds which are untreated. The demand for nitrogen compounds and proteins, etc., required for proper development of the boll would account to some extent for this leaf reddening. If the shortage were sufficiently acute it would result in the disintegration of the proteins

* The increase was from 12·9 per cent. to 17·1 per cent. only.

† *Melilotus parviflora.*

in the chloroplasts to provide the nitrogen required. This again would result in decreased assimilation and a further deficiency of nutrients.

Root Development.

The degree of root growth is of importance to the plant in all stages of development. The greater the root development the greater the volume of soil which can be tapped to provide the necessary water and salts required for the full development of the plant, and as is abundantly clear from the work of Weaver, Jean and Crist [1922] final yield depends to a major degree on root development.

Cotton roots of different ages were washed out at Lyallpur during 1928 and 1929. In 1929 special precautions were taken to obtain uniform soil conditions for the experimental plants. In spite of this, variations in root development appear to be considerable even under apparently uniform conditions (the instance quoted later in the variety U4 serves as an example). Owing to the time required to wash out and to plot the roots to scale, the number of observations must necessarily be limited but if allowance is made for aberrant observations, the general course of root development can be followed from the data obtained.

Various factors have been investigated in connection with root growth. Cannon [1918] implies the existence of optimum soil temperatures for root growth, which may vary with different species. This author also points out [1924, 1925] that it is not possible to separate the effects of soil temperature and the oxygen content of the soil atmosphere, but that " where the partial pressure of oxygen is adequate as in well-tilled soil, the rate of root growth may be modified directly by a change in temperature of the soil." Weaver, Jean and Crist [1922] call soil temperature " an important ecological factor affecting root growth " and say that " like soil aeration it affects the development of the root, not only directly, but also plays a part in the life activities of soil organisms ". They also point out that water-content of the soil is a most important factor affecting root development under field conditions.

In comparisons at Lyallpur of the root development of 3 weeks old seedlings, sown at different dates, and therefore under different conditions of soil temperature, it was found that the average depth to which the roots had penetrated in the earlier sown crop (sown April 1st) was 46 cms., and the average height of the shoot was 12 cms. For similarly aged plants from seed sown on May 1st the height of the shoot was similar, and the roots varied in depth of penetration from 36 cms. to 48 cms. It was noted in the later sown plants that from 32 cms. to 47 cms. depth there were not so many side roots, as in the earlier sown plants. These results should be compared with the results given by Balls [1913, 1919] and other results

obtained at Lyallpur (Table III). The depth of penetration of similarly aged plants in Egypt and at Lyallpur are similar. It should be noted, however, that the soil temperatures in Egypt are somewhat cooler than in the Punjab [Gray and Nassar, 1928] and that the variety of cotton differs in the two countries.

The differences, however, between the depths of penetration of 'normal' and 'frequently watered' plants at Lyallpur is quite marked. Though more frequent waterings reduce soil temperatures, it is the greater availability of water which must most probably be held responsible for the greater root development (*see also* Table VII *later*).

The high soil temperatures at Lyallpur are not necessarily depressant to root growth, but, as has been suggested elsewhere for the connection between soil temperatures and shoot growth [Trought, 1931], high soil temperatures are an indication of the operation of other unfavourable conditions for root growth.

In earlier sections the effect of climate and physiological conditions have been considered as affecting assimilation and nutrient supply. Priestley and Evershed [1922] state that root growth is dependent on the supply of nutrients. This is obviously what would be expected. It can be stated generally, therefore, that there are numerous factors which, by depressing the supply of food material, would be expected to affect adversely the growth of the roots.

The root washing experiments of 1928 and 1929 reveal that there are differences in root development from year to year, as would follow from differences in food supply, and these experiments are rendered more interesting from the fact that there were differences in the final boll development in the two years. The extent of root development is reflected in the extent to which bolls opened well or badly.

The depths to which the roots had penetrated are shown in Table VII.

The date of sowing in 1928 was 5th May and in 1929 the 21st May. In the "frequent watering" plot the number of irrigations was twice the number of irrigations given to the 'normal watering'.

The table shows that there was restricted root growth in 1928 as compared with 1929. The diagrams show that temperatures in May 1928 were higher, humidities less and hours of sunshine more than in 1929. The avoidance of these conditions in 1929 permitted a very considerably increased growth of root in the early stages, even though relative humidities in 1929 were themselves below the normals for May and June.

In 1928 there were very heavy rains about the 118th day after sowing. The figures for 1928, which are corroborated by other unpublished figures, show that after these rains the roots decreased in length, or in other words, that the lower roots died off. The similarity of this result with Balls' [1927] results in which 'asphyxiation' of the lower roots by the rising water-table results in an immediate

drop in the flowering curve, is shown by an examination of the 1928 flowering curves. The flowering curve which was rising rapidly at the end of August falls rapidly from the beginning of September — the rains took place on 29th August and 1st September. The lack of soil aeration consequent on these rains was sufficient to asphyxiate the roots, and cut off the flowering curve earlier than usual. (In 1929, the peak of the flowering curve was on 6th September, in 1927 the curve fell away on the 11th September and in 1926 the mode was on the 16th September — a drop occurred on the 2nd September in this year, but recovery took place.) Furthermore, during Sepetmber and October a considerable root growth is required to keep pace with the needs of the plant. A shortage of nutrients, competition between developing flowers and bolls and water shortage in the soil may combine and operate in such a way that the plant is drawn into a vicious circle. Boll competition may result in decreased root growth, resulting in a shortage of nutrients; shortage of nutrients results in further and fiercer competition between boll and boll with a further decrease in root growth and so on.

In 1928 at the time when boll development was making its greatest demand on the root-system, the root-system was unequal to the task and the bolls opened badly, but in 1929 a great increase in the root-system took place which could therefore cope with this increased demand and the bolls opened well.

The effect of extra watering on root development is shown from the figures in Table VII. Although in the early stages the roots of the more frequently watered plants did not penetrate so deeply, the surface system was greatly increased. The more frequent waterings enabled this surface system to function throughout the plant's life; and during the time when water rather than mineral nutrients were more urgently required, the roots did not penetrate deeply. But the plant was able, when increased root development was necessary, to expand and penetrate more deeply than less frequently watered plants. The increased yield obtained in the watering experiments with increased application of water can thus be explained by the increased root development of which the plant is capable. In these two years also there were " root restriction " experiments laid out. These are briefly described in Appendix A. The type of boll opening in the beds was recorded each year, and the records are reproduced in the Appendix. These show definitely that where there was artificial interference with the normal development of the roots, the boll opening was much worse than in those beds where normal conditions prevailed. In another case, in 1929, two plants, six feet apart and of the same variety (Parnell's Jassid-resistant U4 from South Africa) showed complete bad opening in one plant and complete good opening in the other. The shoots were similar, and the number of bolls approximately equal. On washing out the roots, no difference in soil conditions was

observable, but there was a very great (but unexplained) difference in root development. The root of the badly opened plant was only 63 cms. deep, with comparatively few laterals, while the plant with well opened bolls had roots 184 cms. deep with a copious development of laterals and absorbing roots (Plate XIX).

Root development, then, in as far as it exercises an effect on good or bad nutrition, is seen to be directly connected with, and may exercise a preponderating effect on the good or bad opening of the bolls.

Discussion.

The foregoing pages have provided reasons and evidence showing that during the development of the cotton plant in the Punjab the environmental factors may produce unfavourable reactions in the plant. The suggestion is made that in certain years the effect of unfavourable conditions, climatic and biological, overlap sufficiently to produce a general pathological state in the plant, which shows itself finally in the failure of bolls to develop properly.

If the records (see diagrams) for different years are compared, it will be found that no one climatological factor can be discovered which can be held responsible each year for failures; it will be found, however, on the other hand, that each year a number of unfavourable factors operate at different times.

The comparison will also show that May and early June is the period when all these adverse factors are at their maximum during the cotton growing season. It is obvious that variation from year to year in these climatic data occurs, and that they do not exercise equally severe effects each year. But the total effect in any year may seriously affect the young plant at that stage in its development when the root growth is of more importance than the shoot growth. In the Punjab, then, in the early stages of root development there are numerous factors which can depress root growth, reducing it from its optimum. The 1928 and 1929 root restriction experiments provided a convincing demonstration of the intimate relation between poor root development and subsequent bad boll opening. A healthy and abundant root growth, particularly in the early stages of development, is the first and essential foundation for future healthy growth with ability to resist later unfavourable factors or diseases which may attack the crop.

It is clear that much more attention is required to be given to the crop during its early stages.

In taking individual years, and considering very briefly some of the conditions which obtained, this will be further emphasised.

In 1919, for example, Milne records that the season was very hot and dry till July 20th and that humidities were low in September. The hot and dry conditions

during the young stages of growth appear to have been equally important with the later dry conditions.

In 1921 again, Milne records that the early part of the season was excessively hot and dry, that there was little rain the previous winter, giving the probability of insufficient soil moisture being stored in the soil, and that there were wind and sand storms in September and October.

In 1925, which was a good year, humidities in early May and throughout June and July were high, though as no rain occurred from mid-August to the 24th September, the humidities during that period were much lower than normal. The maximum temperatures in September in 1925 remained about 100°F., and are similar to those recorded in 1919 and 1929, but maximum temperatures in June and July were low. But in 1925 and 1929 (in both of which years boll opening was good) September was " good growing weather ", and, as in 1929 there was good root growth, it seems probably that good root growth also occurred in 1925.

In 1926 (a bad year) there were early high maximum temperatures, and during July and August there was a comparatively severe White Fly attack, combined with a general fungous attack on the leaves. There was also a low winter rainfall in the previous winter, though the actual summer rains were somewhat above normal, and well distributed. The competition factor between developing bolls, due to a rather unusually early rise of the flowering curve, and a late dehiscence of anthers, was also likely to have attained serious proportions in this season. It can be well understood that such a sequence of unfavourable factors could produce failure.

In 1928 though the winter rainfall was not greatly in deficit, there was excessive insolation in May, and there were high maximum air temperatures and low relative humidities in May and August. The soil temperatures were high throughout the season, and there were two particularly heavy rainfalls, one of nearly four inches in July, and one of nearly six inches on the 1st September. Here again there was late anther dehiscence, with an increased flower production in the early part of the flowering period, which would cause a waste of nutrients in the first place, and an increased competition for available nutrients later. The attack of White Fly was not serious on the experimental plots at Lyallpur, yet general bad opening occurred.

Mitigating or Remedial Measures.

(*a*) *Sowing date.*—It is clear that the first obvious remedy would be to sow the crop at such a time (either earlier or later) that these factors did not operate at that period of development when the crop was most susceptible. This remedy has already been discussed [Trought, 1931] and experimental data have been published on the effect of later sowing dates [Trought, 1930] from which it will be clear that

sowing 4F cotton about the middle of June had a beneficial effect on the yield obtained, and may decrease bad opening in such crops.

(*b*) *Agricultural Practice.*—There are, however, other possibilities. Good cultivation, or good agricultural practice, is all directed to mitigating the climatic effect in one way or another, in order that the crop plant will have a less severe fight to establish itself and produce its final yield. Crop production in any climate implies cultivation of some sort, but the more severe the climate the higher the standard of cultivation required. In the Canal Colonies of the Punjab, it is not realised that even with the extensive irrigation systems which have been built, the climate is still an arid climate, and that many of the principles of "dry-farming" require to be applied [Widtsoe, 1921] in spite of the remarkable regularity with which irrigation water is supplied to the farmer.

The sowing of cotton in lines to allow of inter-cultivation afterwards is an essential and should be considered a commonplace. This practice on the basis of experiment has been recommended by the Punjab Agricultural Department for years, but unfortunately has not been adopted universally by the *zemindar*. All the more scientific and intelligent *zemindars* sow in lines, and get better yields (*vide* Himbury, [1929], referred to above) and unless this practice is adopted cultivations after sowing are almost impossible, with the result that there is much unnecessary water loss. Reverting to the comparison with Egypt, where the crop is sown on ridges, hand cultivation is practised as long as it is possible to get between the plants.

(*c*) *Irrigation Practice.*—Balls [1913] has shown that in the milder climate of Egypt the cotton crop loses, in transpiration and soil evaporation, considerably more water than is put on in irrigation. The growth curves of 4F [Trought, 1931 and Diag. XI] supply evidence that throughout its development, cotton in the Punjab is water-short, and that there is a loss of water from the soil during the crop's growth is shown by soil moisture determinations.

It is clear then that the storing of water in the soil [Widtsoe, 1921] for the cotton crop is one of the first necessities of good cultivation. It is interesting to note that, even in Egypt, where there is a water-table within a few feet of the surface, that nine or ten waterings are given during the season (some 25-30 acre inches) and generally at least three ploughings requiring one or two irrigations, are given prior to sowing. In contrast with this, five waterings may be considered as rather above average in the Punjab, supplemented by the rainfall.

It cannot, however, be sufficient merely to water the land coming under cotton two or three times prior to sowing. The land must be ploughed and cultivated and left in good tilth. Two or three waterings before sowing also have the effect of cleaning the land of weeds, which form another potential source of water loss.

If the land is covered with weeds, more water will be lost than from ordinary bare soil.

A further effect of pre-sowing waterings will be the reduction of soil temperature, and the encouragement of the growth of the soil bacteria and protozoa.

The figures for root growth given earlier show the advantage of early waterings after sowing instead of allowing the crop to wait as long as possible. This might in practice require some adjustment with the irrigation needs of other crops, and naturally the extra growth induced thereby may lead to an increased necessity for more water later. But as shown by the watering experiments conducted at Lyallpur, the more water which is given to the crop the greater the yield; even though the crop may actually show the "failure" symptoms referred to earlier.

(*d*) *Manuring*.—Green manuring, or the application of farmyard manure, can also be recommended in so far as this practice assists the soil in its retention of water, and may have an additional effect by increasing the CO_2 evolution from the soil. The application of artificial manures, particularly late in the season, has been shown to increase the actual outturn, but such treatment can only be considered in the light of a palliative measure. The main object should be to get the land into such good heart that the plant is able to obtain its own mineral nutrients without the assistance of artificial manures.

It cannot be expected, however, entirely to eliminate failures by these means. The climate of the Punjab is an extremely severe one and the type of cotton which has already been produced by acclimatisation and selection is extremely hardy. In spite of this, however, as suggested by Mr. B. C. Burt*, the trouble may still be largely varietal. It is a general experience that American cottons which do well in other parts of India, or which are imported direct from America or other cotton growing countries invariably fail to perform satisfactorily in the Punjab. The symptoms of this invariable failure are similar to those which occur from time to time in 4F. 4F is an improvement and in many years gives excellent yields, but is still far from perfect, and further improvement is possible. It seems then that the final solution of the problem must be looked for in the production of a new variety which will be able to make a continuous and healthy growth under as bad a combination of environmental conditions as may occur. It has been observed that a Mollisoni cotton, which, in common with other *desi* types of cotton, is very seldom affected by the kind of under-development of the boll which has been under discussion in the case of American varieties, is able to produce an extensive root-system under conditions of drought. What is necessary is an American variety which is capable of producing an adequate root-system under similar adverse conditions. The process may be slow and is rendered difficult by the fact that the

* In a private communication to the author.

root development which is a major factor in maintaining this healthy condition is extremely difficult to observe.

Summary and Conclusions.

The established fact of large variations in yield from year to year of 4F cotton in the Punjab is due to " failures " in certain years.

The symptoms of these failures are described, and their possible causes discussed.

Diseases and pests may play a part but are not initiating factors, they are a consequence of other factors.

The effect of climatic and physiological factors are described, and the importance of root development emphasised.

The deduction is drawn that in failure years the overlapping effect of a series of adverse factors operating at comparatively short intervals of time, do not permit of the recovery of the plant before it matures its crop, and results in the failure of the plant to produce properly developed lint and seed. The plant is most susceptible in its early stages, at which time adverse factors are at their maximum. The factors re-act on root development reducing it from its optimum.

The adoption of good agricultural practice will assist in mitigating the effect of these adverse factors, but a complete solution can probably only be obtained by the discovery of a type of plant still more resistant to the severe climatic conditions which prevail.

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Appendix A.

ROOT RESTRICTION EXPERIMENTS, 1928-29, AT LYALLPUR.

4F seed was dibbled in lines 3′ 6″ apart in holes 15″ apart along the lines, using 15-20 seeds per hole. The holes were thinned to 2 plants per hole.

There were three treatments and nine repetitions of each treatment, arranged as recommended by Engledow & Yule (Empire Cotton Growing Review, Vol. III, 1926).

The first treatment (Brick Floor) consisted of removing the top layer of soil from each of the nine beds and putting down a layer of bricks 12″ below the surface covering the area, and mortared together. Rows of holes for drainage were left at uniform intervals. These beds were left at the same level as adjoining beds when the soil was refilled in.

The second treatment (Disturbed) consisted of removing the top layer of soil to a depth of twelve inches and replacing it. It is probable that in doing this a slight pan was formed, as was found by Balls in his Terraces Experiment at Giza (Balls W. L. Analysis of Agricultural Yields, Pt. III, Proc. Roy. Soc. Series B., Vol. 208, 1917).

In the third treatment (Undisturbed) the soil was left undisturbed.

The experiment was continued on the same plot for two successive years, and height measurements, and flowering and bolling curves, recorded. These are not reproduced. The ' pan ' effect was, however, shown in both years by the " Disturbed " beds, which never quite equalled the " Undisturbed " beds. The " Brick Floor " beds were worse than either of the other two in growth, flowering and bolling.

The following table, however, shows the type of boll opening observed in each bed of each treatment in the two years.

Type of Boll Opening Recorded.

	Brick Floor	Disturbed	Undisturbed
1928	1. Bad	2. Good.	3. Quite nice.
	4. Normal	5. Good.	6. Normal.
	7. Poor.	8. Not very good	9. Quite well.
	10. Bad	11. Bad	12. Fairly good.
	13. Better than 1, 4, 7, 10.	14. Normal	15. Not good.
	16. Bad	17. Bad	18. Not very good.
	19. Poor.	20. Not good	21. Fairly satisfactory.
	22. Very poor	23. Normal	24. Satisfactory.
	25. Better than 16, 19, 22.	26. Quite good.	27. Very good.

Type of Boll Opening Recorded—contd.

	Brick Floor	Disturbed	Undisturbed
1929	1. Bad	2. Quite good. . .	3. Very good.
	4. Bad	5. Small bad patch only .	6. Very good.
	7. Bad except for a few plants.	8. Very good . . .	9. Very good.
	10. Very bad . . .	11. Very good . . .	12. Very good.
	13. One plant with good opening.	14. Very good . . .	15. Good.
	16. Generally bad . .	17. Quite bad . . .	18. Opening quite well.
	19. Very bad . . .	20. Good	21. Very good.
	22. Bad	23. Quite good . . .	24. Quite good.
	25. Very bad . . .	26. Medium . . .	27. Very good.

In the "Brick Floor" beds the lines of plants were so arranged that no plants came above the openings in the brick floor for drainage, so that no tap-root could grow straight down below 12".

The plot was considered to be of rather better than average fertility for cotton, which would account for the fairly satisfactory opening obtained in the "Disturbed" and "Undisturbed" beds in the bad year 1928. The land was fallow between one cotton crop and the next.

TABLE III.

(See also Table VII.)

Age of plant	GIZA			LYALLPUR, 1928.				Age of plant
	W. L. B. 1919	W. L. B. 1913		Watered normally		Watered twice normally		
		Depth of root	Height of shoot	Depth of root	Height of shoot	Depth of root	Height of shoot	
	Cms.	Cms.	Cms.	Cms.	Cms.	Cms.	Cms.	
5 days .	6	..	..	..	..	..	..	..
7 „ .	14	..	..	..	..	..	..	..
14 „ .	20	..	..	..	..	..	..	..
7 weeks .	55	50	10	30	17·5	45	19·1	6 weeks
11-12 weeks.	..	90	45	80	34·2	82*	39·3	10-11 „
14-16 „ .	140	130	85	144	47·5	173†	52·5	15 „
18-19 „ .	..	180	120	..	..	..	..	..
21-23 „ .	..	200	130	213	..	..	..	20 weeks

* More extensive "active" root-system than normal waterings.
† Volume occupied by roots was much greater than in normal watering.

TABLE IV.

Weekly means of Humidities at 8-0 a.m. at Lyallpur, Lahore and Dera Ismail Khan.

Week ending	1926			1927		
	Lyallpur	Lahore	Dera Ismail Khan	Lyallpur	Lahore	Dera Ismail Khan
June 9th	26·0	37·3	38·1	33·0	40·0	30·7
June 16th	25·6	33·6	38·6	38·9	54·9	39·4
June 23rd	43·1	50·0	50·1	39·4	51·7	38·4
June 30th	41·6	38·8	42·0	48·5	47·2	47·7
July 7th	37·7	40·4	46·1	55·3	64·1	56·1
July 14th	65·3	74·3	69·6	70·7	74·4	62·7
July 21st	72·0	75·4	69·4	59·4	79·3	57·1
July 28th	64·7	73·0	70·3	79·7	90·8	68·8
August 4th	71·1	78·8	64·6	69·1	83·4	64·7
August 11th . . .	78·8	84·7	66·6	61·3	83·6	63·0
August 18th . . .	84·0	89·4	75·3	72·0	83·7	65·0
August 25th . . .	76·7	84·7	66·6	75·6	73·9	68·4
September 1st . . .	76·9	86·7	70·3	79·7	76·6	67·7

TABLE IV—*contd.*

Weekly means of Humidities at 8-0 a.m. at Lyallpur, Lahore and Dera Ismail Khan.

Week ending	1928			1929		
	Lyallpur	Lahore	Dera Ismail Khan	Lyallpur	Lahore	Dera Ismail Khan
June 9th	50·6	54·3	60·0	38·8	41·7	40·6
June 16th	60·0	59·7	54·4	55·3	57·0	59·8
June 23rd	51·3	46·4	39·8	48·9	59·1	55·4
June 30th	45·8	46·7	49·4	53·6	68·7	47·1
July 7th	69·6	73·1	67·6	57·8	67·3	68·0
July 14th	68·7	65·1	64·5	58·8	63·3	63·0
July 21st	56·6	58·6	58·4	80·6	80·1	72·7
July 28th	75·9	75·6	72·9	79·7	79·0	80·6
August 4th	57·3	64·4	60·8	71·8	82·9	76·6
August 11th . . .	53·8	56·6	61·3	70·4	75·1	74·9
August 18th . . .	55·4	60·0	67·0	56·5	63·6	64·0
August 25th . . .	65·1	72·4	64·8	76·1	81·4	77·0
September 1st . . .	81·7	82·0	68·0	78·3	87·5	68·1

TABLE V.

Maturation period and shedding percentage of flower buds labelled on their first appearance.

Date of labelling	1928								
	289 F			4 F			Mollisoni *		
	Number labelled	Average maturation period in days	Percentage matured	Number labelled	Average maturation period in days	Percentage matured	Number labelled	Average maturation period in days	Percentage matured
July 3, 1928 . .	71	28	1·4	..	..	..	22	27·1	40·9
July 10, 1928 . .	75	..	0	..	..	..	42	32·7	7·1
July 16, 1928 . .	86	39·8	15·1	69	37·3	33·3	92	..	0
July 23, 1928 . .	83	35·6	24·2	78	33·4	28·0	88	29·5	2·3
July 30, 1928 . .	62	31·0	1·6	84	30·0	1·2	83	28·5	2·4
Aug. 6, 1928 . .	51	..	0	78	32·0	55·0	78	..	0
Aug. 13, 1928 . .	41	..	0	68	31·0	61·7	71	..	0
Aug. 20, 1928 . .	44	33·1	67·0	65	33·4	72·3	59	31·1	47·4
Aug. 27, 1928 . .	33	32·0	66·6	50	35·8	68·0	42	31·4	59·5
Sep. 3, 1928 . .	34	31·9	67·5	..	..	..	24	31·1	64·7
Sep. 10, 1928 . .	18	35·8	89·0	..	..	..	10	31·7	60

NOTE—Mollisoni buds were labelled one day later, and 4 F buds two days later than date in column.

* *G. Indicum* var *Mollisoni* of Gammie.

TABLE V—*contd.*

Maturation period and shedding percentage of flower buds labelled on their first appearance—contd.

Date of labelling	1929											
	289 F			4 F			Early Strain*			Mollisoni		
	Number labelled	Average maturation period in days	Percentage matured	Number labelled	Average maturation period in days	Percentage matured	Number labelled	Average maturation in days	Percentage matured	Number labelled	Average maturation in days	Percentage matured
July 12, 1929 .	38	..	0	43	..	0	45	29·2	51·1	48	29·6	14·6
July 19, 1929 .	28	..	0	22	..	0	39	30·2	79·5	45	27·9	73·3
July 26, 1929 .	41	39·7	36·6	31	39·3	39·0	38	29·4	73·7	46	27·3	67·4
Aug. 2, 1929 .	..	..	..	..	....	..	47	30·6	68·1	93	29·7	65·6
Aug. 9, 1929 .	91	35·3	63·7	64	36·6	59·4	44	32·8	68·2	34	30·8	58·8
Aug. 16, 1929 .	86	33·9	66·3	85	34·6	42·3	44	31·6	52·2	8	24·5	50·0
Aug. 23, 1929 .	99	33·8	67·7	97	31·0	24·7	49	32·6	26·5	..	..	..
Aug. 30, 1929 .	76	34·7	60·5	12	34·3	66·7	..	..	..	..	..	..

NOTE—Mollisoni and Early Strain buds were labelled one day later than date in column.
* *A. G. Hirsutum* type.

TABLE VI.

Water loss from soil during growth of cotton crop.

[Figures to nearest 10, in cubic-metres or metric tons.*]

—	—	Water added by irrigation and rain	Difference between original and final moisture in soil to 9′ depth	Total water loss per acre	Water loss per day
		Cubic-metres.			
1928 .	Plot watered every three weeks.	2,280	—490	2,770	17·6
	Plot watered every five weeks.	1,870	—830	2,700	17·2
	Fallow unirrigated from July 2.	1,140	+1,000	140	..
1929 .	Plot watered every three weeks.	2,910	—160	3,070	19·5
	Plot watered every five weeks.	1,940	—470	2,410	15·4
	Fallow unirrigated from May 21.	1,070	—310	1,380	..
1928 .	Fallow irrigated and cultivated.	1,990	+670	1,320	..
1929 .	Fallow irrigated and not cultivated.	2,700	+200	2,500	..

* 1 metric ton = 0·98 tons approx.

TABLE VII.

Age of plant in days		Normal watering		Age of plant in days		Frequent watering	
		Depth of penetration of roots in cms.				Depth of penetration of roots	
1928	1929	1928	1929	1928	1929	1928	1929
..	32	..	70	..	31	..	62
44	..	30	..	42	..	44	..
..	63	..	110	..	61	..	88
73	..	80	..	77	..	82	..
..	110	..	148	..	96	..	216
104	..	144	..	108	..	173	..
..	125	..	140	..	128	..	224
147	..	213	..	140	..	120	..
..	157	..	180	..	159	..	268
..	190	..	240	..	189	..	300
218	..	120	..	206	..	124	..

TABLE VIII.

Percentage distribution of shed 4F bolls by age.

Year	1927			1928			1929		
Age of bolls in days	1-5	5-10	Over 10	1-5	5-10	Over 10	1- 5	5-10	Over 10
June . .	58·2	36·5	5·3	..	..	..	..	..	..
July . .	78·5	19·6	1·9	90·8	8·2	1·0	..	..	..
August . .	66·7	31·5	1·8	81·5	15·2	3·3	73·8	19·0	7·2
September .	..	..	..	36·8	44·5	18·7	43·2	44·6	12·2
October . .	..	..	..	22·2	48·7	29·1	31·5	53·5	15·0
General Average	72·6	25·2	2·2	52·6	32·8	14·6	42·2	45·2	12·6

Percentage of flowers which matured bolls.

—	1927*	1928†	1929†
July	3·5	2·2	..
August	46·5	8·5	21·5
September	24·5	36·0	46·4
October	10·0	17·8	16·9
August to October together .	31·2	25·0	44·2

* Percentage actual bolls matured.

† Percentage flowers not shed.

The percentage flowers not shed would be rather greater then the percentage of bolls matured, owing to the difficulty of certainty in the collection of labels from the ground.

TABLE IX.

Percentages of well opened and medium or badly opened American Cotton Crops from observations taken during 1927 and 1928 on zemindars' fields.

		Well opened	Medium or badly opened	Remarks
		Per cent.	Per cent.	
1927 . .	Total .	40·8	59·2	49 observations.
	After wheat . .	36·6	63·3	30 observations.
	After toria . .	..	100	4 observations only.
	After fallow or other crops.	60·0	40	14 observations.
1928 . .	Total .	18·5	81·5	168 observations.
	After wheat . .	14·1	85·9	78 observations.
	After toria . .	16·6	38·4	12 observations.
	After fallow or other crops.	23	77	78 observations.

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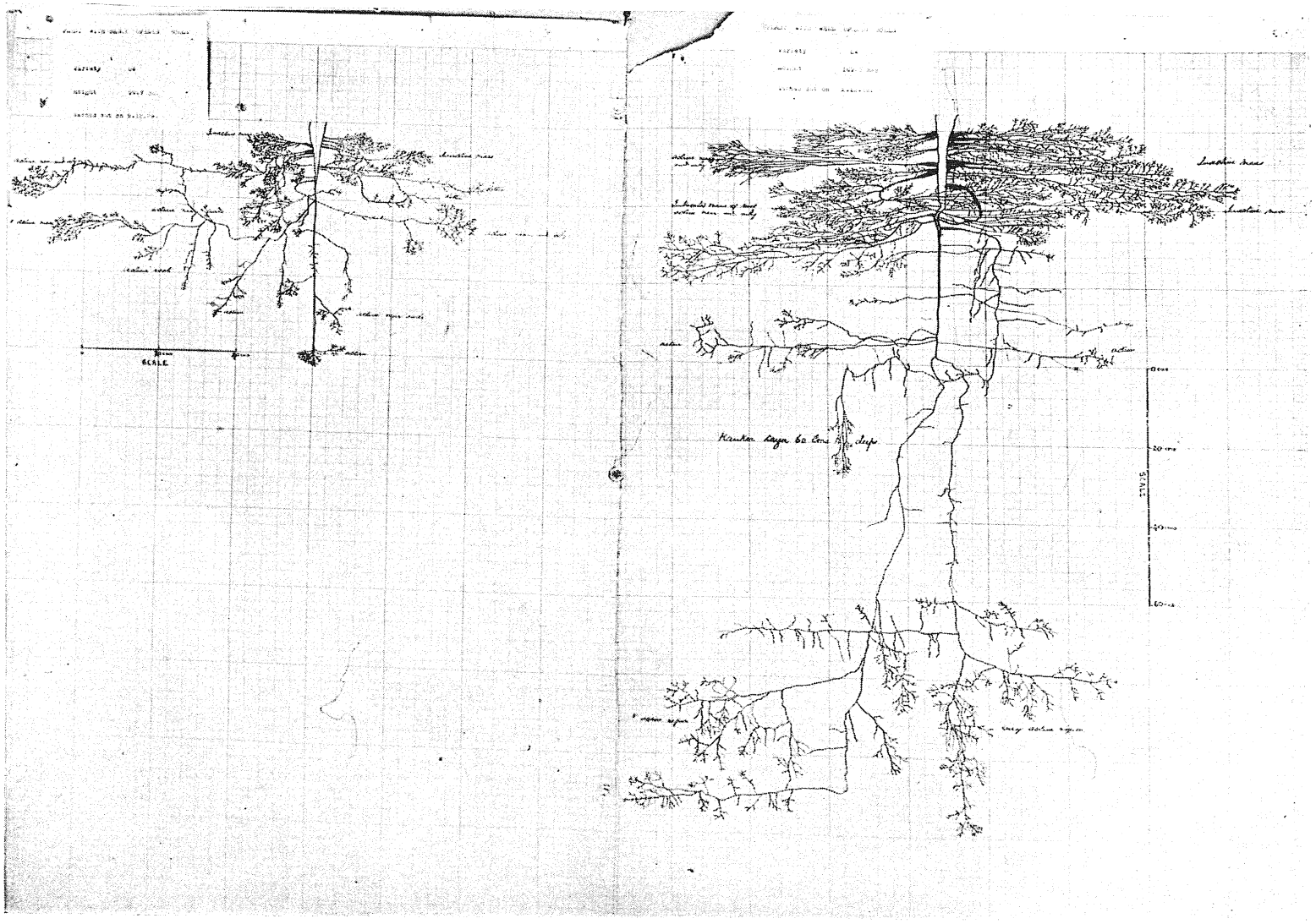
*Seen in abstract only.

Diagrams of root-system of two plants of U 4 cotton grown at Lyallpur in 1929.



A

B

A Plant with bad opening in all bolls ; Height of shoot 99·7 cms. Number of bolls on plant.
B. Plant with good opening in all bolls ; Height of shoot 109·5 cm.. Number of bolls on plant.

PLATE XIX.

Diagram I.—Weekly Means of Max. and Min. Air Shade Temps., Lyallpur, 1926-29.

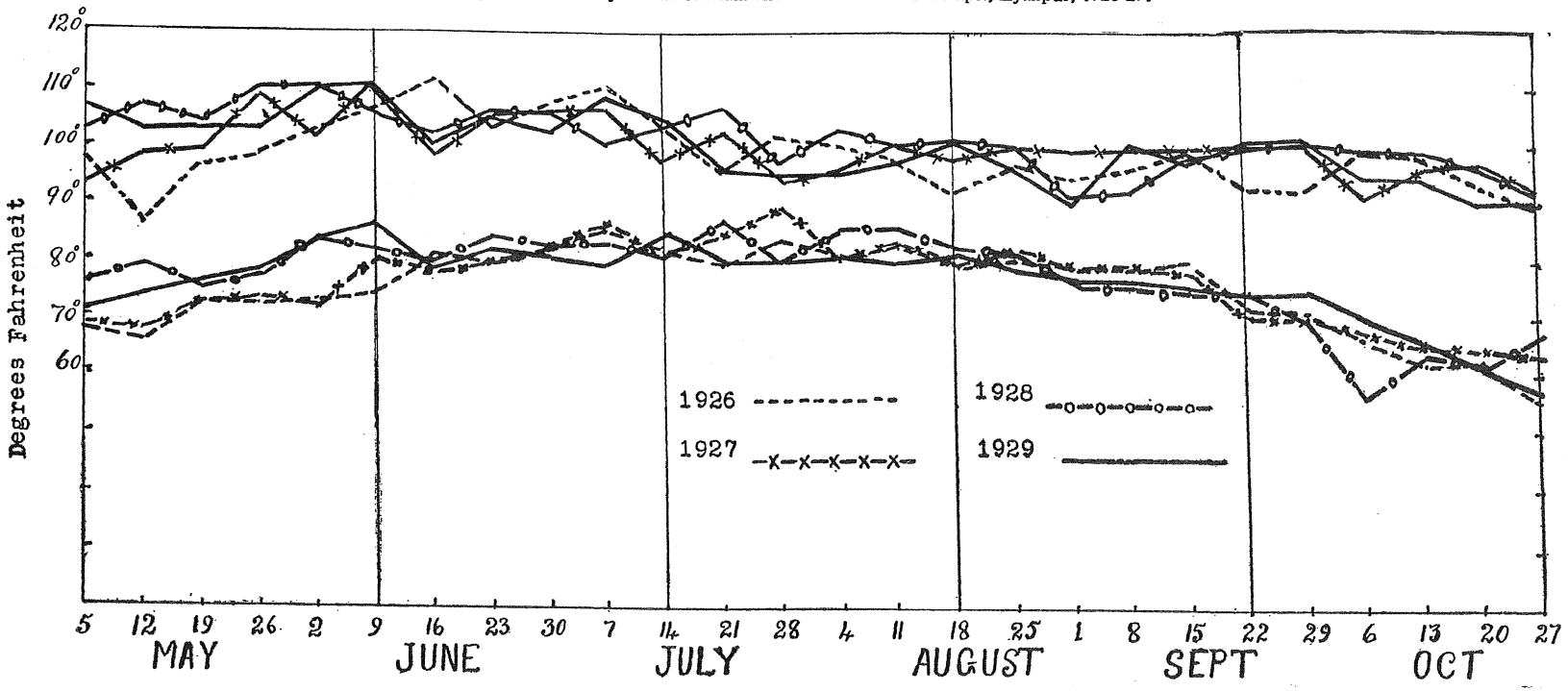


Diagram II.—Weekly Means of Soil Temps. at 5 cms. depth, Lyallpur, 1926-29.

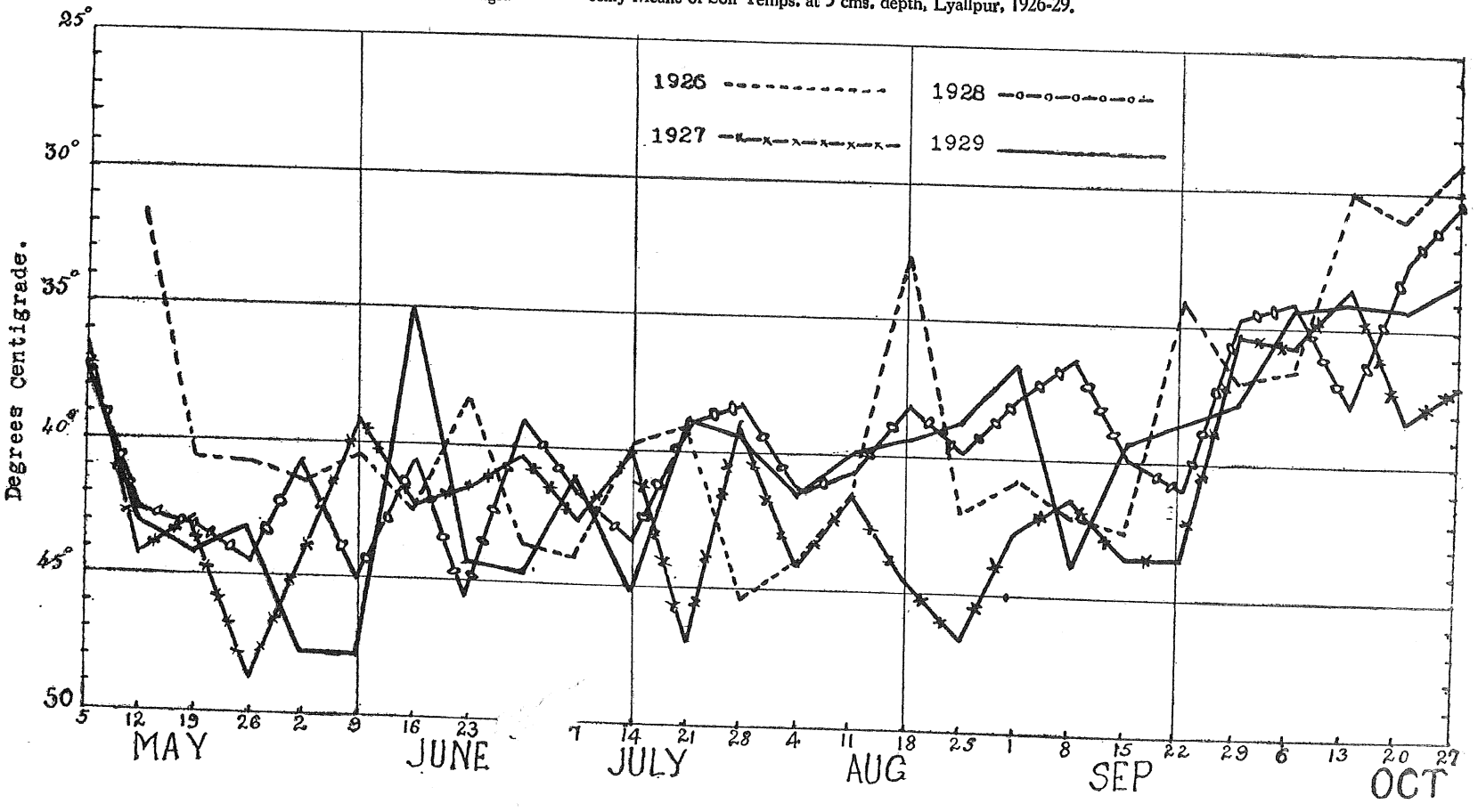


Diagram III.—Weekly Means of Daily Hours of Sunshine, Lyallpur, 1927-29.

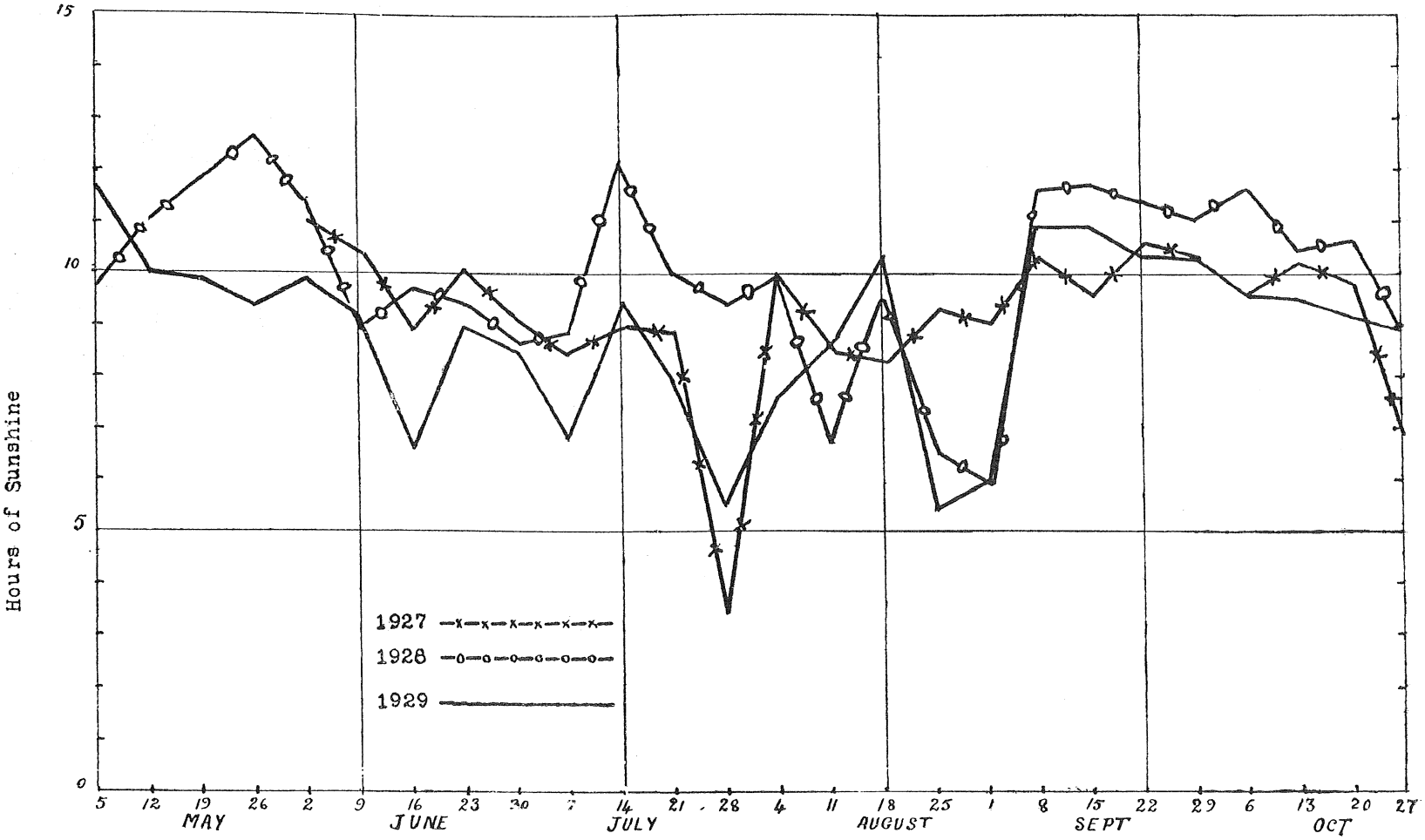


Diagram IV.—Weekly Means of 8-0 A.M. Relative Humidities, Lyallpur, 1926-29.

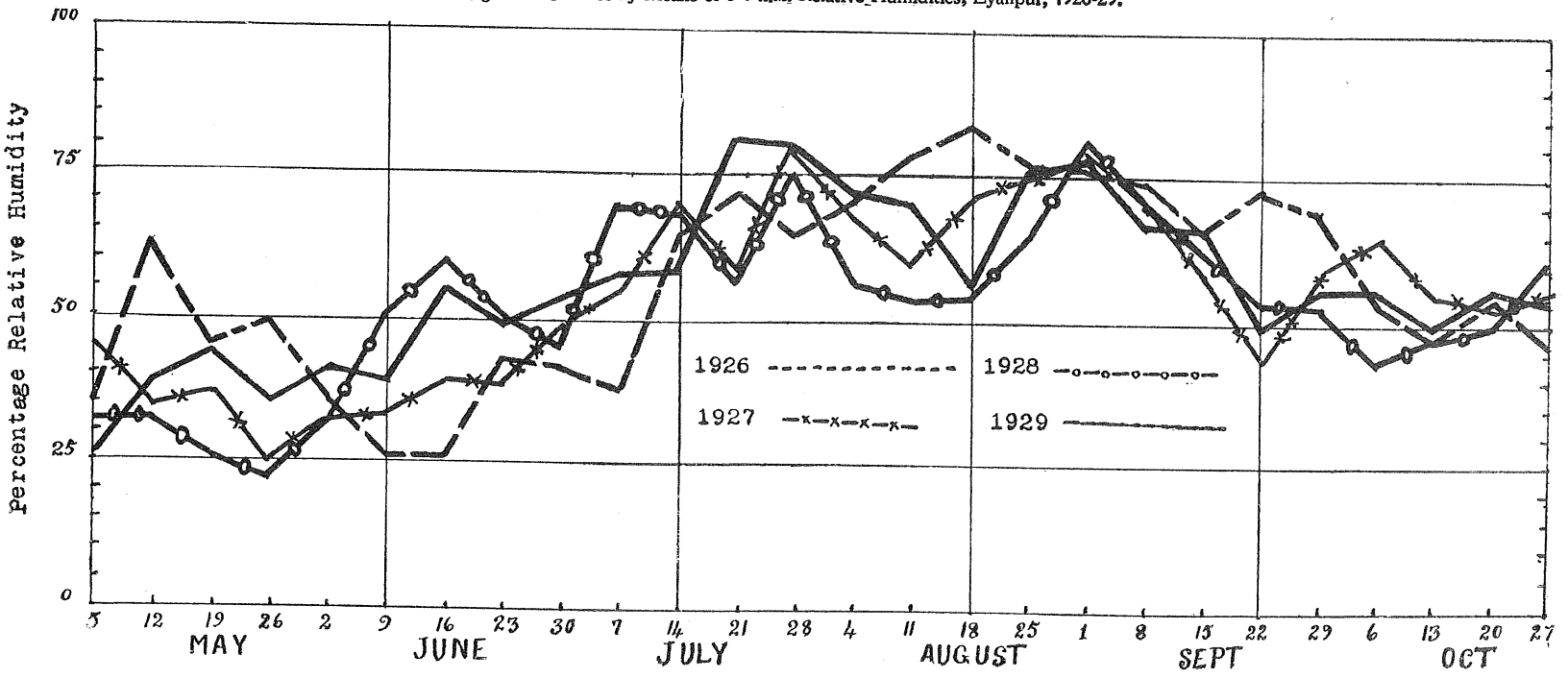


Diagram V.—Weekly Means of Evaporation from Piche Cantoni Atmometers sited in the Cotton Crop, with the Evaporating disc 16½" above ground level, Lyallpur, 1926-29.

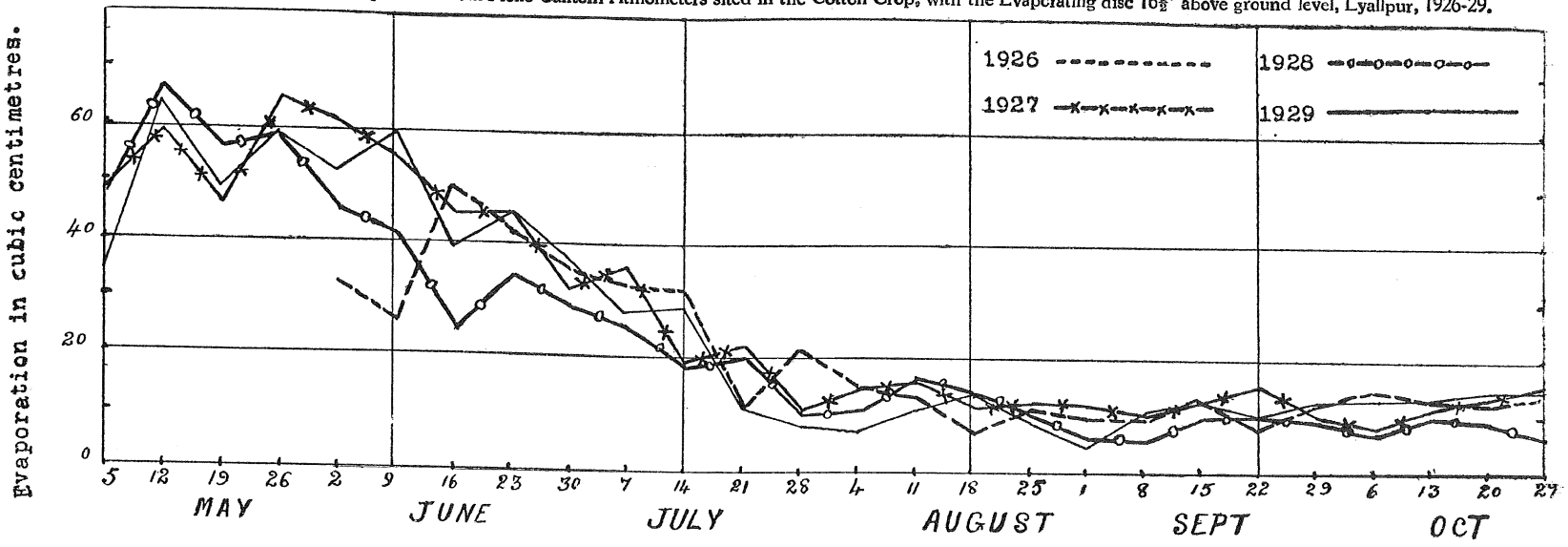


Diagram VI.—Flowering Curves per plant per day of 4-F, Lyallpur, 1926-29.

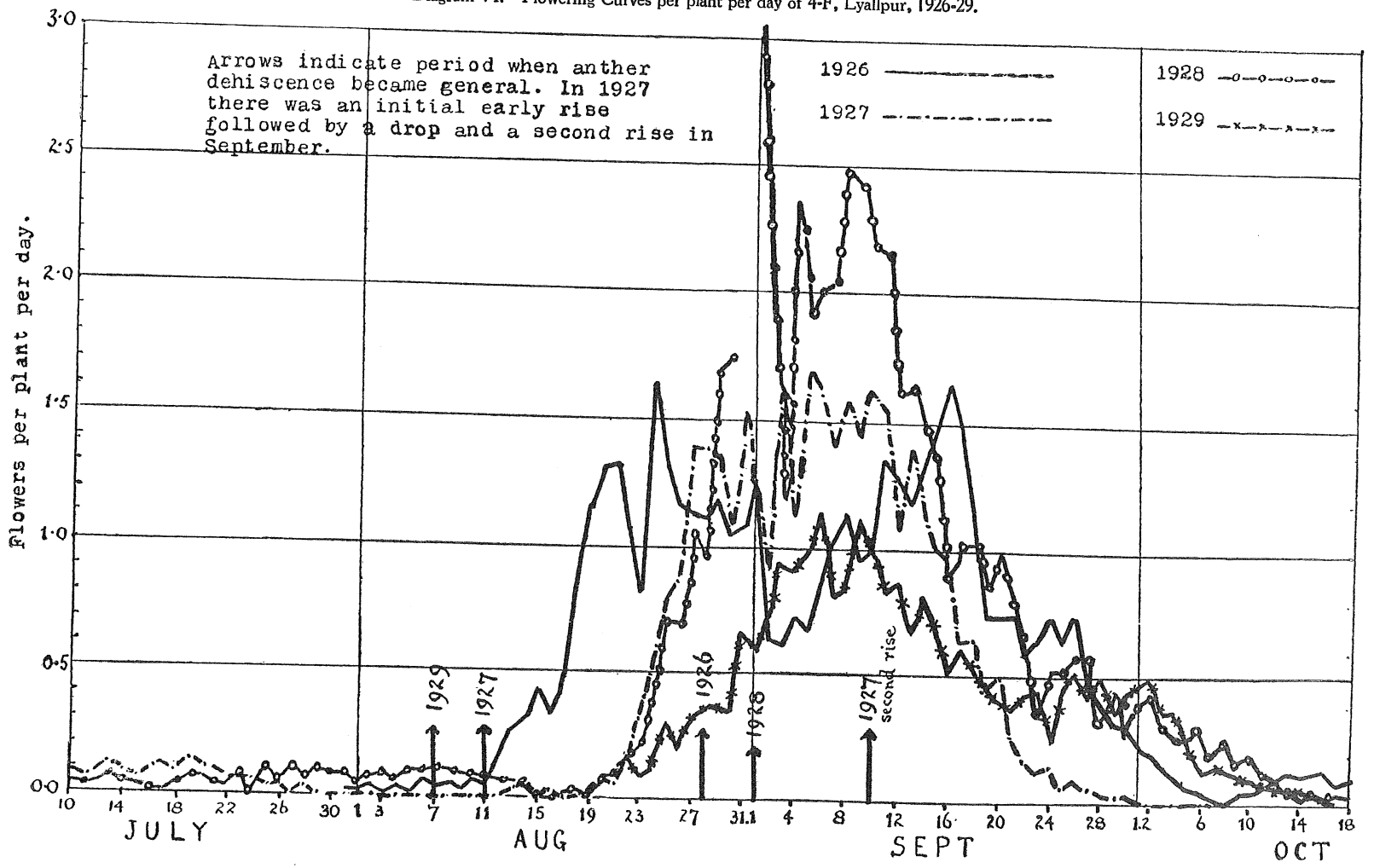
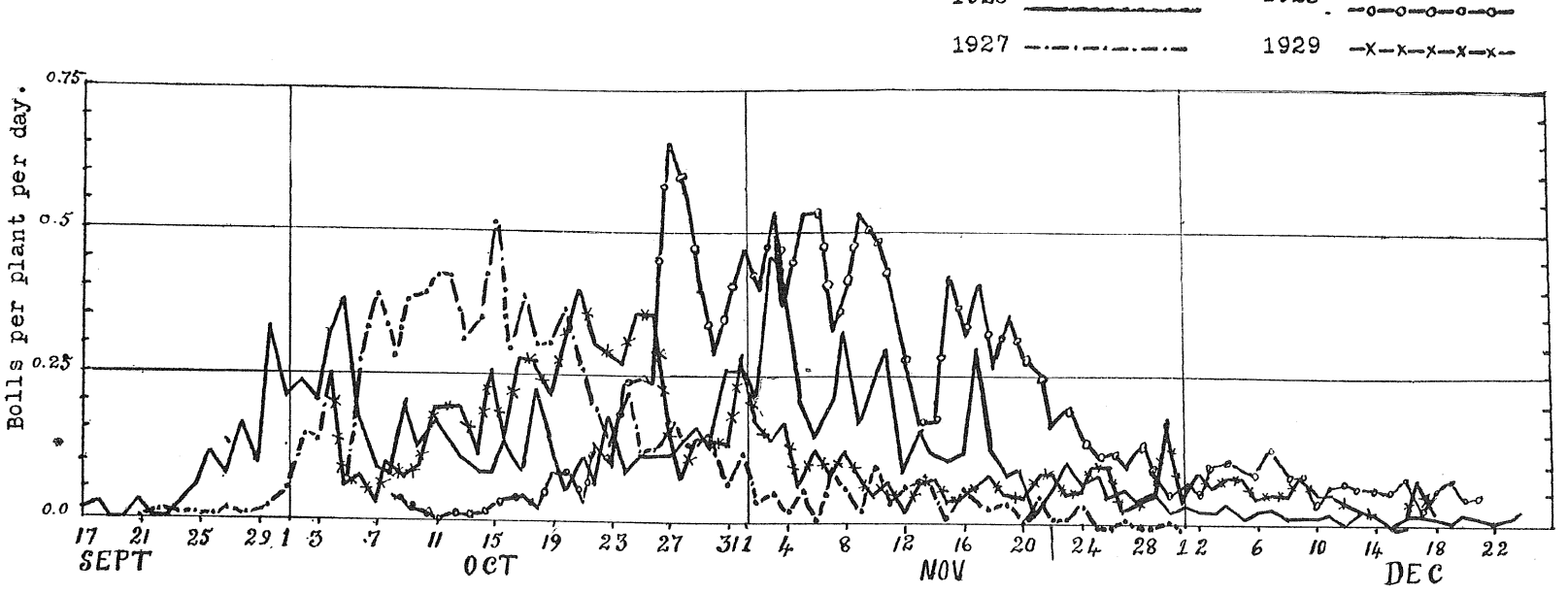


Diagram VII.—Bolling Curves per plant per day of 4-F at Lyallpur, 1926-29.



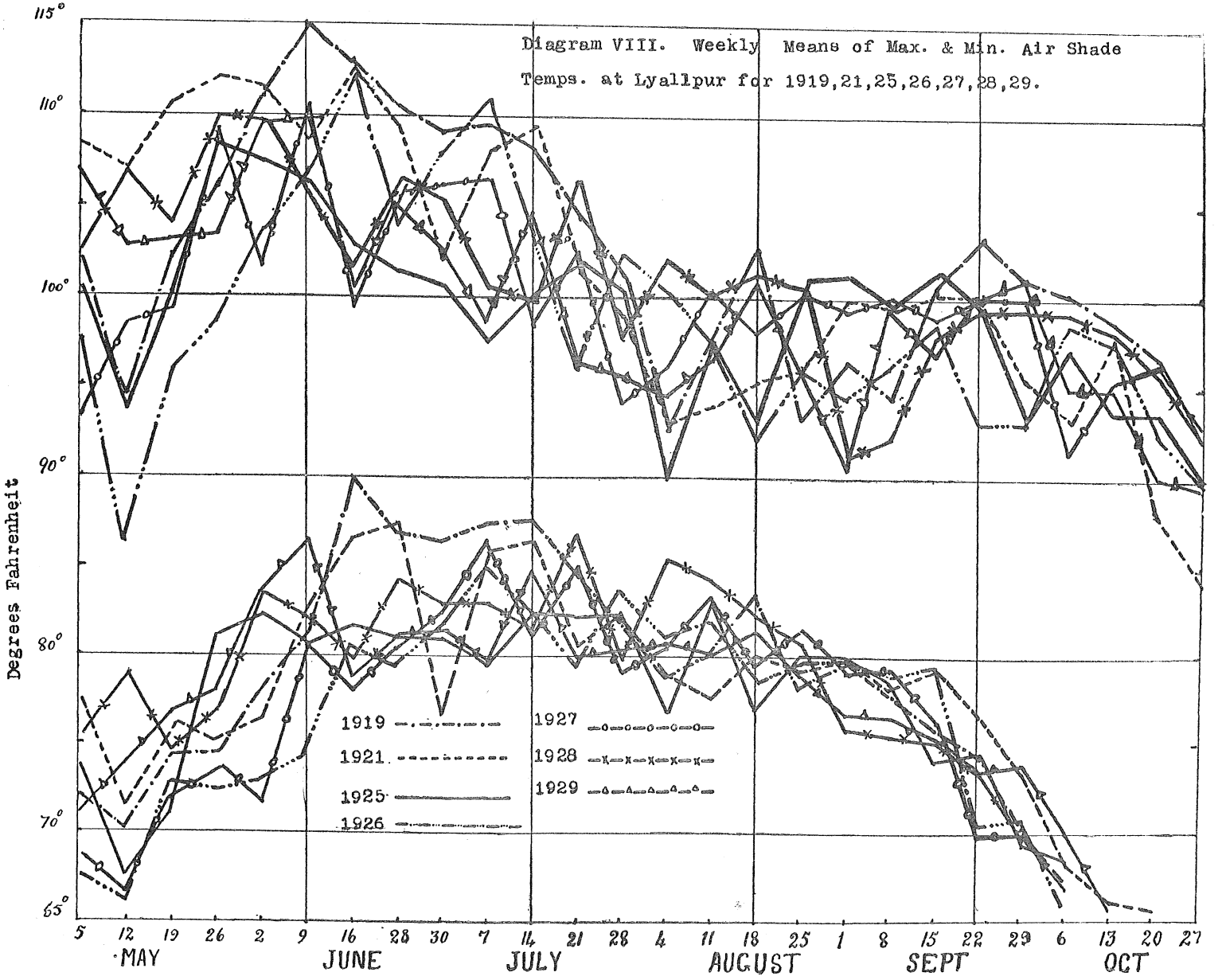
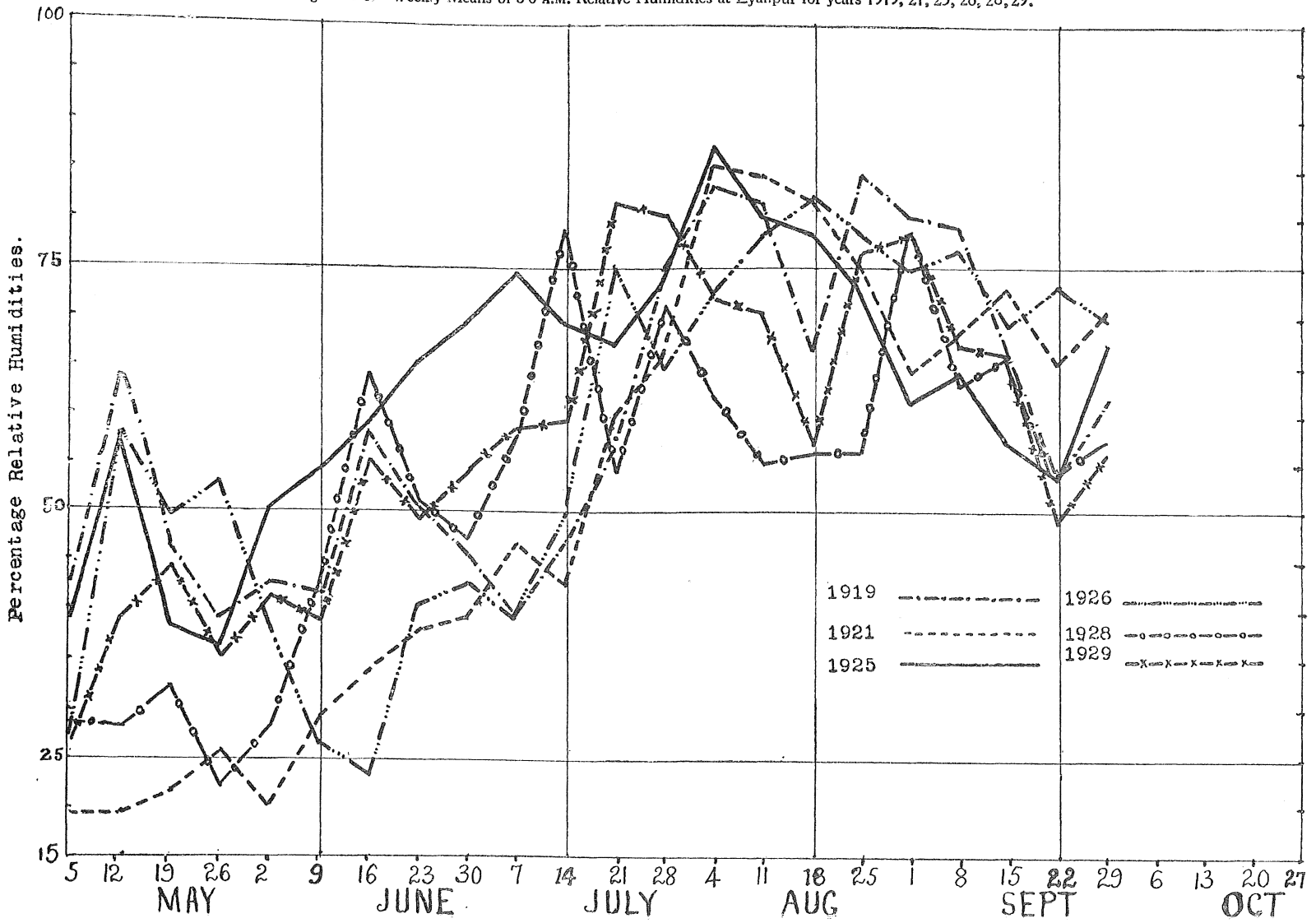


Diagram VIII. Weekly Means of Max. & Min. Air Shade Temps. at Lyallpur for 1919,21,25,26,27,28,29.
Degrees Fahrenheit
115°
110°
100°
90°
80°
70°
65°
1919
1921
1925
1926
1927
1928
1929
5 12 19 26 2 9 16 23 30 7 14 21 28 4 11 18 25 1 8 15 22 29 6 13 20 27
MAY
JUNE
JULY
AUGUST
SEPT
OCT

Diagram IX.—Weekly Means of 8·0 A.M. Relative Humidities at Lyallpur for years 1919, 21, 25, 26, 28, 29.



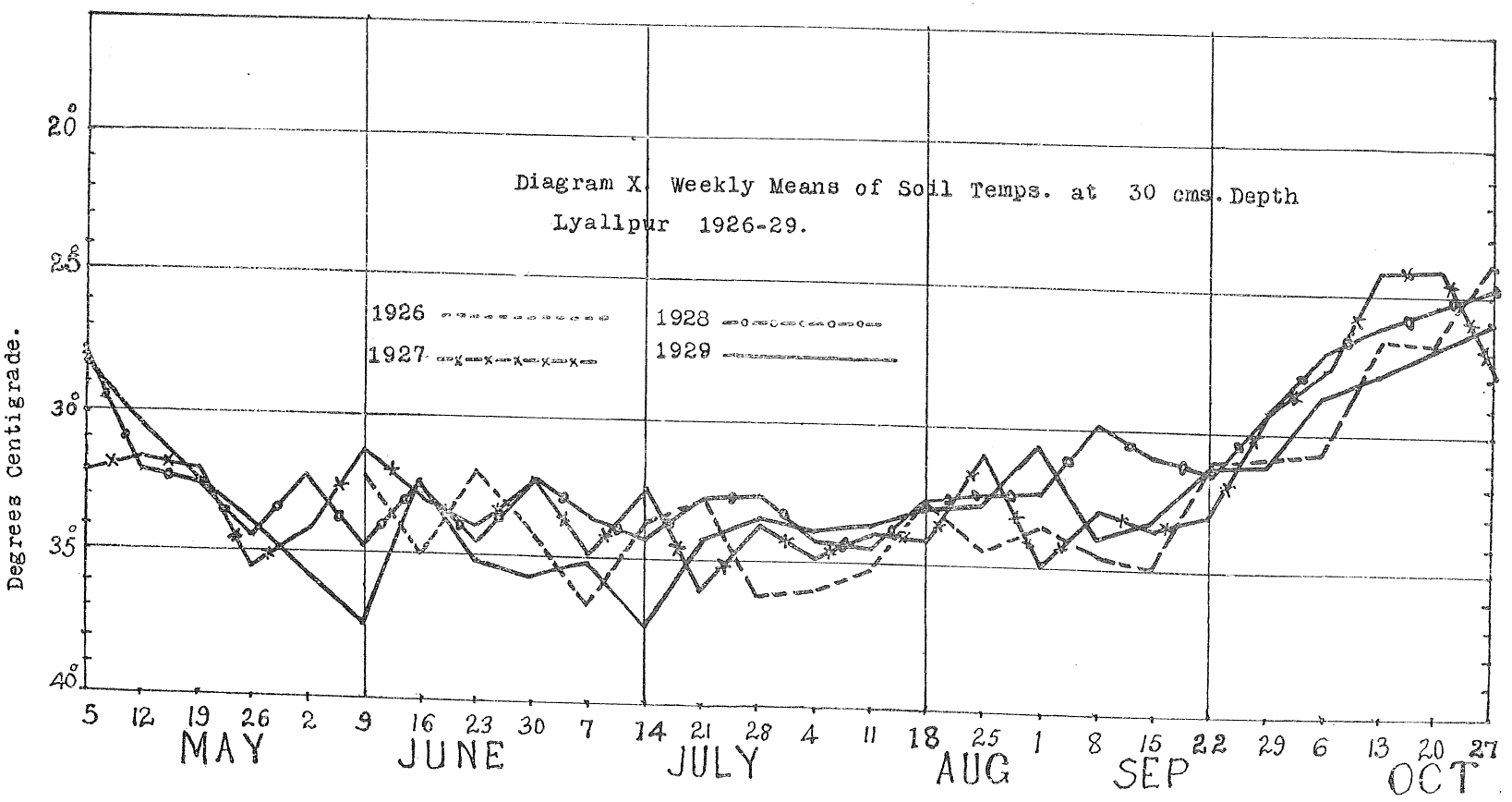
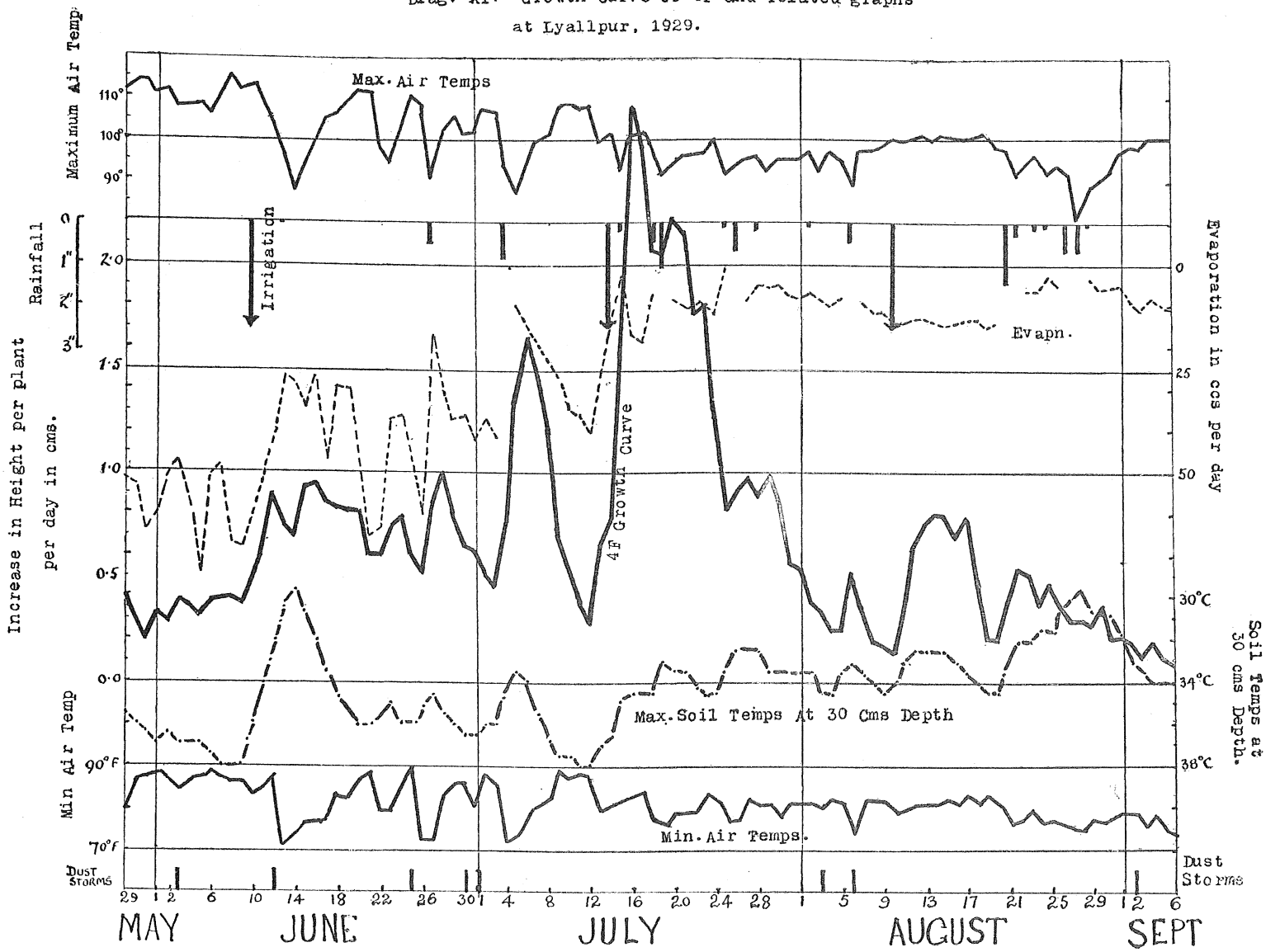


Diagram X. Weekly Means of Soil Temps. at 30 cms. Depth
Lyallpur 1926-29.
1926
1927
1928
1929
Degrees Centigrade.
20°
25°
30°
35°
40°
5 12 19 26 2 9 16 23 30 7 14 21 28 4 11 18 25 1 8 15 22 29 6 13 20 27
MAY
JUNE
JULY
AUG
SEP
OCT

Diag. XI. Growth Curve of 4F and related graphs
at Lyallpur, 1929.



RICE-BREEDING IN THE CENTRAL PROVINCES.

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(With Plates XX to XXXII.)

The purpose of this article is to review briefly the position which rice occupies in the agriculture of this province and to give some account of the results which have been achieved in rice-breeding work in progress here and to indicate the possibility of further work yielding useful results.

The paramount importance in the Central Provinces of a crop, such as rice, which occupies nearly 5,112,444 acres, or an area equivalent to 30 per cent. of the total cropped land, requires but little emphasis. The areas where it is largely grown fall into three tracts. The first is situated in the north of the province and includes the district of Jubbulpore and parts of Mandla and Damoh. The second tract lies in the Wainganga valley running from Seoni to Chanda and includes the southern parts of Seoni, the low areas of Balaghat and the eastern portions of Bhandara and Chanda. The third and the most important tract consists of the plain of Chhattisgarh division in the east of the province. The bulk of the produce is consumed within the province, but it is obvious that in a crop which constitutes the chief diet of a very large section of the agricultural population, the cumulative effect of improvement, however small, must go a long way towards the economic emancipation of the cultivator.

The rice species (*Oryza sativa*) is wonderfully rich in varieties, and this fact is the best indication of the great possibilities of improvement in this crop. It is difficult to ascertain with any degree of preciseness the number of varieties met with in these provinces, owing to the confused state of nomenclature—the same variety being known by a different name in a different locality. Also instances are not wanting of markedly different rices being known by the same name. Rani kajar for example (Plate XXVII) is the name applied to several rices differing in colour of outer glumes

and size of kernel. The crop grown at present consists in the majority of cases of a mixture of strains of different cropping power and quality. The chief problems which confronted us in the work of improvement, therefore, were :—

(1) The isolation and comparative testing of varieties.

(2) Improvement of selected varieties by raising high-yielding strains from single plant selections.

(3) The raising of new strains combining the desirable and useful diagnostic characters of two or more varieties by hybridization.

The first step naturally consisted in making a collection of as many samples as possible with a view to raising pure lines from these. As a result of this work a large number of very useful varieties, described hereafter, were isolated. Selection work was next concentrated in these varieties. The method adopted was as follows. Over a thousand plants were selected in the field from each variety, and out of this number 50 best plants were retained for line cultures. The length of each line and the number of plants per line were kept constant. Yield records were carefully maintained, and by elimination, the number under trial was brought down to five strains, which were further tested against each other in duplicate plots until the best strain was finally retained. Work on these lines has resulted in strains of uniform quality and high cropping power.

Description of the Improved Varieties.

1. *Gangi kuda selection E. B. 17.*—Leaf-sheath light purple. Auricles, band and ligule colourless. Ears exserted, curved, drooping. Apiculus purple. Stigma deep purple. Ripe grains straw coloured with dirty brown markings in some furrows. Glume and palea slightly convex. Kernels medium in size (6·1 m. m. × 2·6 m. m.×1·8 m. m.), translucent. (Plate XX ; Plate XXX, fig. 3.)

This has been found to be the best rice among the early varieties and is in much demand in Jubbulpore district.

2. *Bhata gurmatia No. 9.*—Leaf-sheath purple. Auricles, band and ligule light purple. Ears exserted, curved. Apiculus purple. Stigma black purple. Ripe grains straw coloured. Glume and palea slightly convex. Kernels medium in size (6·0 m. m.×2·5 m. m.×1·9 m. m.), translucent, sometimes with a chalky deposit of abdominal white. (Plate XXI, fig. 1.)

This is recommended as one of the best early rices for unirrigated lighter soils of Chhattisgarh division. First isolated by this Section in 1916, it has since been considerably improved by selection.

3. *Bhondu No. 10.*—Leaf-sheath green. Auricles, band and ligule white. Ears exserted, curved, approximate. Apiculus coloured like inner glumes. Stigma white. Ripe grains with light brown furrows, nerves pale. Glume convex. Palea

slightly convex. Kernels medium in length, coarse (6·1 m. m.×3·1 m. m.×2·2 m. m.), with chalky deposit of abdominal white well developed; almost opaque. (Plate XXII, fig. 2.)

Isolated by the Section in 1918, selected strains in this variety have proved to be the best of all the medium varieties in respect of yield.

4. *Parewa No. 22.*—Leaf-sheath pink. Auricles and band dark purple. Ears exserted, curved, drooping. Apiculus purple. Stigma black purple. Ripe grains brown. Glume and palea slightly convex. Kernels medium (6·3 m. m.× 2·7 m. m.×1·7 m. m.), translucent, sometimes with a chalky deposit of abdominal white. (Plate XXIII, fig. 1.)

The distinct colour of the band and the auricles in this medium variety constitute useful distinguishing characters in a field infested with wild rices.

5. *Surmatia No. 11.*—Leaf-sheath black purple. Auricles, band and ligule purple. Ears exserted, curved. Stigma black purple. Ripe grains straw coloured with prominent black apiculus. Glume and palea slightly convex. Kernels medium (6·2 m.m.×2·3 m.m.×1·7 m.m.), translucent. (Plate XXII, fig. 1.)

The colour of the leaf-sheath renders the elimination of wild rice an easy matter.

6. *Gurmatia No. 17.*—Leaf-sheath purple. Auricles, band and ligule light purple. Ears enclosed, curved. Apiculus and stigma black (purple. Ripe grains straw coloured. Glume and palea slightly convex. Kernels medium (6·2 m.m.× 2·5 m.m.×1·9 m.m.), translucent. (Plate XXIV; Plate XXXI, fig. 1).

This is a heavy-yielding, late variety largely grown in Chhattisgarh division.

7. *Luchai No. 4.*—Leaf-sheath green. Auricles, band and ligule white. Straw strong. Ears exserted, curved, approximate. Apiculus like outer glumes. Stigma white. Ripe grains of golden colour. Glume and palea slightly convex. Kernels medium and fine (6·0 m.m.×2·2 m.m.×1·6 m.m.), translucent. (Plate XXI, fig. 2.)

This is the heaviest-yielding, late variety of good quality.

8. *Chinoor No. 21.*—Leaf-sheath green. Auricles, band and ligule white. Ears exserted, curved, spreading. Apiculus common. Stigma white. Ripe grains straw coloured. Glume straight, awned. Palea straight. Kernels long, fine (7·0 m.m.× 2·1 m.m.×1·7 m.m.), translucent. (Plate XXV; Plate XXX, fig. 2.)

This late scented variety is reckoned to be one of the finest rices of the Province.

9. *Dilbuksha No. 35.*—Leaf-sheath green. Auricles, band and ligule white. Straw weak. Ears much exserted, drooping; branches separate and drooping. Apiculus common. Stigma white. Ripe grains straw coloured. Glume convex. Palea slightly convex. Kernels very short and coarse (4·8 m.m.×2·2 m.m.× 1·6 m.m.), translucent. (Plate XXVI; Plate XXX, fig. 1.)

A late variety of good quality and yield. It is in great demand in Jubbulpore district.

The average yield obtainable from these improved strains is given below* :—

Variety		Yield per acre	Remarks
Bhata gurmatia	Early	2,076 lbs.	(Average of 5 years) 1925-26 to 1929-30.
Bhondu	Medium	2,647 ,,	(Average of 4 years) 1925-26 to 1928-29.
Parewa	,,	2,170 ,,	(Average of 3 years) 1925-26 to 1927-28.
Surmatia	,,	2,315 ,,	(Average of 4 years) 1925-26 to 1928-29.
Deshi medium	,,	2,220 ,,	(Average of 5 years) 1925-26 to 1929-30.
Gurmatia	Late	2,494 ,,	(Average of 5 years) 1925-26 to 1929-30.
Luchai	,,	2,372 ,,	(Average of 4 years) 1925-26 to 1928-29.
Chinoor	,,	2,403 ,,	(Average of 3 years) 1925-26 to 1927-28.
Deshi Late	...	2,334 ,,	(Average of 5 years) 1925-26 to 1929-30.
E. B. No. 17	Early	1,223 ,,	(Average of 3 years) 1927-28 to 1929-30.
Dilbuksha	Late	960 ,,	(Average of 2 years) 1927-28 to 1928-29.

* Annual Reports of the Department of Agricultu e, C. P.

It has been said elsewhere that the number of varieties of rice grown here is very large. Though no claim is made to our having made a complete agricultural and botanical survey of all the varieties in existence, it has been possible to introduce a system of classification wherein all the rice varieties can be placed, thus rendering easy further breeding work on this crop. This scheme of classification is based upon grain and leaf-sheath characters as will be seen below :—

Kernels white. 1. Very short. (Less than 5 m.m. in length.)

(*a*) Slender.

(*b*) Fine.

(*i*) Ripe grains straw coloured.

* Leaf-sheath green . . . . . Krishnabhog (4·24×1·74×1·22)

(*c*) Medium.

(*i*) Ripe grains straw coloured.

* Leaf-sheath green . . . . . Hiranakhi (4·44×2·15×1·5).
Kubrimohar (4·45×2·2×1·42).

(*ii*) Ripe grains brown.
* Leaf-sheath green . . . . . Padamphul (4·44×2·17×1·38).

(*d*) Coarse.
(*i*) Ripe grains straw coloured.
* Leaf-sheath green . . . . . Dilbuksha (4·8×2·2×1·6).
Harad gundi (4·1×2·49×1·53).

(*iii*) Ripe grains black.
* Leaf-sheath green . . . . . Tulsimangir (4·4×2·36×1·7).
** Leaf-sheath coloured . . . . . Rani kajar (4·4×2·23×1·66).

(*e*) Round.
(*i*) Ripe grains straw coloured.
* Leaf-sheath green . . . . . Dongermanki (4·0×2·73×1·76).

(*iii*) Ripe grains black.
* Leaf-sheath green . . . . . Maknuja (3·95×2·9×2·1).

2. Kernels short. (Less than 6 m.m. in length).
(*b*) Fine.
(*i*) Ripe grains straw coloured.
* Leaf-sheath green . . . . . Mohan bhog (5·25×1·77×1·29).
Baghmuchh (5·67×1·83×1·43).
** Leaf-sheath coloured . . . . . China kapur (5·3×2·07×1·53).

(*ii*) Ripe grains brown.
* Leaf-sheath green . . . . . Kubri mohar (5·85×2·0×1·56).

(*c*) Medium.
(*ii*) Ripe grains brown.
* Leaf-sheath green . . . . . Zurai (5·54×2·34×1·54).

(*d*) Coarse.
(*ii*) Ripe grains brown.
* Leaf-sheath coloured . . . . . Badriphal (5·15×2·76×1·83).

(*iii*) Ripe grains black.
* Leaf-sheath coloured . . . . . Bare hansa (5·2×2·66×1·85).

(*e*) Round.
(*i*) Ripe grains straw coloured.
* Leaf-sheath green . . . . . Makka (5·35×3·06×2·1).

3. Kernels medium. (Less than 7 m.m. in length.)
(*a*) Slender.
(*i*) Ripe grains straw coloured.
* Leaf-sheath green . . . . . Basmati (6·04×1·77×1·45).

(*ii*) Ripe grains brown.
* Leaf-sheath green . . . . . Pithadi (6·55×1·73×1·45).

(*b*) Fine.
(*i*) Ripe grains straw coloured.
* Leaf-sheath green . . . . . Basmatia (6·4×2·0×1·6).

(*ii*) Ripe grains brown.
* Leaf-sheath green . . . . . Luchai (glumes golden) (6·0×2·2×1·6).
Chhitrakot (6·0×1·96×1·42).

** Leaf-sheath coloured . . . . . Banspatri (6·17×2·12×1·6).

(*iii*) Ripe grains black.
*Leaf-sheath green . . . . . Kali kamod. (6·34×2·18×1·65).

(*c*) Medium.
(*i*) Ripe grains straw coloured.
* Leaf-sheath green . . . . . Ludka. (6·05×2·38×1·76).
Dhaur. (6·9×2·6×1·71).

(*ii*) **Leaf-sheath coloured . . . . . Gangi kuda. (6·1×2·6×1·8).

(Bhata gurmatia, (6·0×2·5×1·9) Gurmatia, (6·2×2·5×1·9) Surmatia) (6·2×2·3×1·7).

(*ii*) Ripe grains brown.
*Leaf-sheath green . . . . . Pisso. (6·8×2·67×1·8).

**Leafs-heath coloured . . . . . Parewa. (6·3×2·7×1·7).

(*iii*) Ripe grains black.
*Leaf-sheath green. . . . . Radha balam. (6·5×2·4×1·8).

(*d*) Coarse.
(*i*) Ripe grains straw coloured.
*Leaf-sheath green . . . . . Bhondu (furrows brown). (6·1×3·1×2·2).
Gatta. (6·12×2·9×1·9).

**Leaf-sheath coloured . . . . . Chipda. (6·12×3·0×1·8).

(*ii*) Ripe grains brown.
**Leaf-sheath coloured . . . . . Suwapankhi. (6·43×2·94×2·0).

(*iii*) Ripe grains black.
**Leaf-sheath coloured . . . . . Karya gurmatia. (6·0×2·82×2·06).

4. Kernels long. (Less than 8 m. m. in length.)
(*a*) Slender.
(*i*) Ripe grains straw coloured.
*Leaf-sheath green . . . . . Jhinidhan. (7·02×1·7×1·61).
(*b*) Fine.
(*i*) Ripe grains straw coloured.
*Leaf-sheath green . . . . . Chinoor. (7·0×2·1×1·7).
**Leaf-sheath coloured . . . . . Rani kajar. (7·22×1·9×1·64).
(*c*) Medium.
(*i*) Ripe grains straw coloured.
*Leaf-sheath green . . . . . Rago. (7·75×2·2×1·84).
(*ii*) Ripe grains brown.
*Leaf-sheath green . . . . . Anterbed. (7·38×2·27×1·72).
(*d*) Coarse.
(*i*) Ripe grains straw coloured.
*Leaf-sheath green . . . . . Ruibuta. (7·02×2·55×1·8).
(*ii*) Ripe grains brown.
**Leaf-sheath coloured . . . . . Sironj. (7·86×2·5×1·82).
6. Kernels very long. (More than 8 m.m. in length.)
(*i*) Ripe grains straw coloured.
**Leaf-sheath coloured . . . . . Aranpapai. (8·18×2·08×1·8).

(See Plate XXVII.)

In addition to the work described above a considerable amount of hybridization work has also been carried out since the year 1925—the chief aim being to obtain a heavy-yielding strain which could be easily distinguished from the wild rices which infest the rice fields of the cultivator. Ordinarily the majority of the cultivated rices are very difficult to distinguish from the wild rices until the time of formation of the ears, the leaf-sheath in both cases being either green or purple. The variety Parewa, however, is an exception to this rule, as it possesses dark purple auricles, by virtue of which it can be easily distinguished in the field. Unfortunately it is comparatively speaking, a poor cropper.

Hybridization was, therefore, resorted to with a view to combining the high yielding capacity of Bhondu with the dark purple auricles of Parewa and black purple leaf-sheath of Surmatia. The success attained in this direction has indeed been very gratifying, and we are to-day in a position to recommend fixed hybrids B. × P. No. 22, B. × P. No. 12 and B. × S. No. 23 (Plate XXVIII, fig. 2; Plate XXXII, figs. 1, 2; Plate XXVIII, fig. 1; Plate XXXII, fig. 3; Plate XXIX; Plate XXXI, fig. 2; Plate XXXII, fig. 4) combining all the desired characters referred to above.

The process involved a detailed study of the flowering and pollination and was rendered difficult by the smallness of the percentage of setting, *viz.*, 10 per cent., which we were able to obtain. The following table shows the time of opening and duration of flower in strain No. G. 17 :—

Flowers opened	Flowers closed	Duration
9·41	10·11	30. min.
9·46	10·20	34. ,,
9·56	10·26	30. ,,
10·15	10·40	25. ,,
10·15	10·50	35. ,,
10·28	11·12	44. ,,
10·50	11·17	27· ,,
10·51	11·17	26. ,,
10·55	11·25	30. ,,
10·55	11·22	27. ,,
10·55	11·31	36. ,,
10·57	11·27	30. ,,
10·59	11·28	29. ,,
11· 7	11·42	35. ,,
11·18	11·43	25. ,,
11·21	11·52	31. ,,
11·45	12·15	30. ,,
12· 8	12·40	32. ,,
12·35	12·57	22. ,,

The anthers burst almost exactly at the time of opening of the flowering glumes (Plate XXIII, fig. 2), and self-pollination is therefore the rule. Instances of natural cross-fertilization, however, are not uncommon in this province.

The study of the inheritance of characters will form the subject of a separate paper, and it is not proposed to give here more than a brief history of our two important crosses. The following statement shows the parental characters, the

characters of the first hybrid generation, and the segregation obtained in the F_2 generation :

Bhondu.		×	*Parewa.*
Leaf-sheath—	Green	Leaf- sheath—	Pink.
Band and Auricles—	White.	Band and Auricles—	Dark purple.
Stigma—	White.	Stigma—	Black purple.
Apiculus—	Common.	Apiculus—	Purple
Ripe grains	-With brown furrows, nerves pale.	Ripe grains—	Brown.
Kernels—	Coarse.	Kernels—	Medium.

F_1

Leaf-sheath—	Pink.
Band and Auricles—	Dark purple.
Stigma—	Black purple.
Apiculus—	Purple.
Ripe grains—	With brown furrows, nerves pale.
Kernels—	Rather coarse.

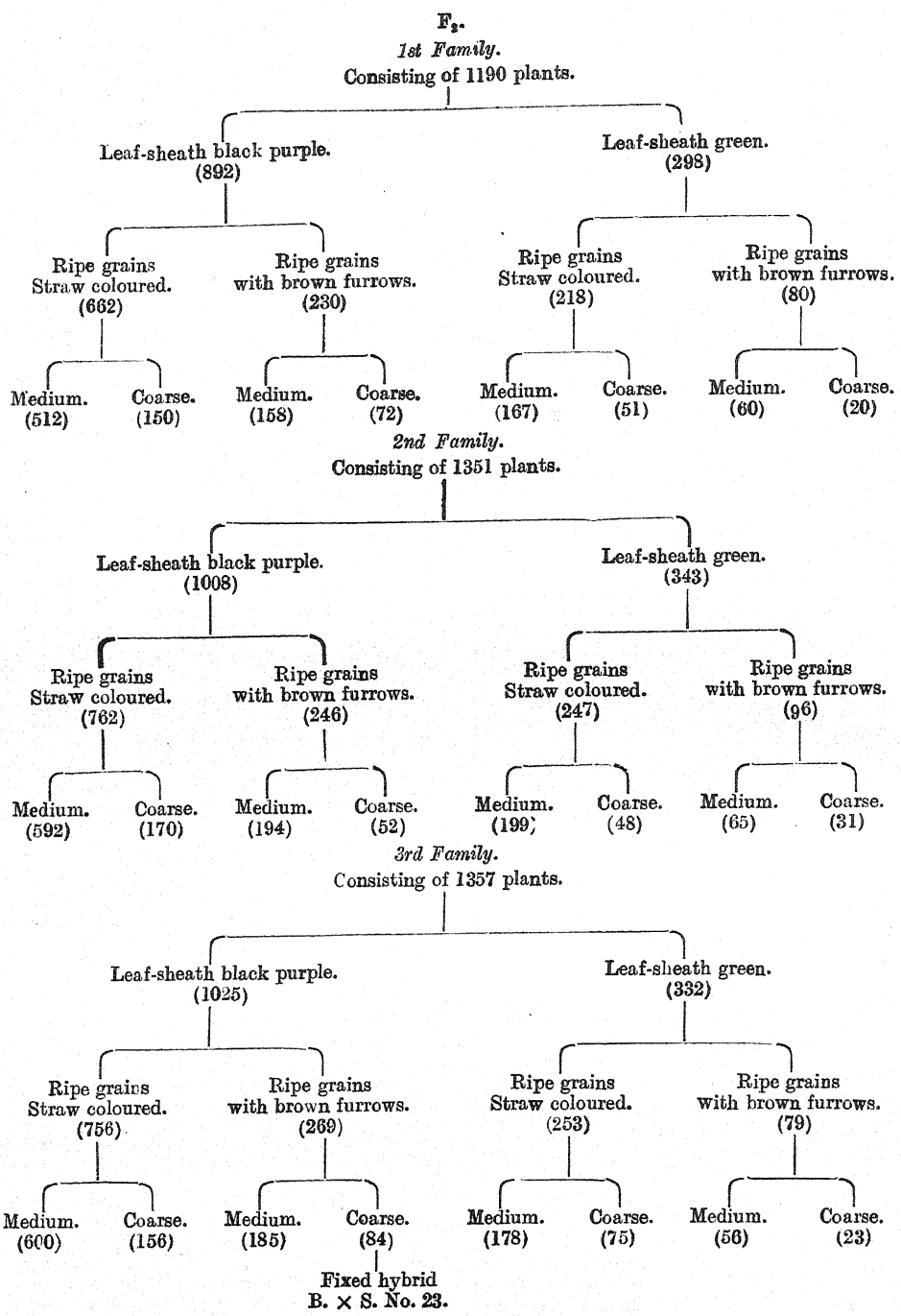
F_2. Family.
Consisting of 2451 plants.

- Leaf-sheath pink. Band and Auricles dark purple. Stigma black purple. Apiculus purple. (1815)
  - Ripe grains with brown furrows, nerves pale. (1343)
    - Medium. (1018)
    - Coarse. (325) → Fixed hybrid B.×P. No. 22.
  - Ripe grains Brown. (472)
    - Medium. (334)
    - Coarse. (138) → Fixed hybrid B.×P. No. 12.
- Leaf-sheath green. Band and Auricles white. Stigma white. Apiculus common. (636)
  - Ripe grains with brown furrows, nerves pale. (462)
    - Medium. (341)
    - Coarse. (121)
  - Ripe grains Brown. (174)
    - Medium (132)
    - Coarse. (42)

Bhondu.	×	*Surmatia.*
Leaf-sheath—Green.		Leaf-sheath—Black purple.
Stigma—White		Stigma—Black purple.
Ripe grains—With brown furrows, nerves pale.		Ripe grains—Straw coloured with black apiculus.
Kernels—Coarse.		Kernels—Medium.

F_1.

Leaf-sheath—Black purple.
Stigma—Black purple.
Ripe grains—Straw coloured with black apiculus.
Kernels—Medium,


F2.
1st Family.
Consisting of 1190 plants.
Leaf-sheath black purple. (892)
Leaf-sheath green. (298)
Ripe grains Straw coloured. (662)
Ripe grains with brown furrows. (230)
Ripe grains Straw coloured. (218)
Ripe grains with brown furrows. (80)
Medium. (512)
Coarse. (150)
Medium. (158)
Coarse. (72)
Medium. (167)
Coarse. (51)
Medium. (60)
Coarse. (20)
2nd Family.
Consisting of 1351 plants.
Leaf-sheath black purple. (1008)
Leaf-sheath green. (343)
Ripe grains Straw coloured. (762)
Ripe grains with brown furrows. (246)
Ripe grains Straw coloured. (247)
Ripe grains with brown furrows. (96)
Medium. (592)
Coarse. (170)
Medium. (194)
Coarse. (52)
Medium. (199)
Coarse. (48)
Medium. (65)
Coarse. (31)
3rd Family.
Consisting of 1357 plants.
Leaf-sheath black purple. (1025)
Leaf-sheath green. (332)
Ripe grains Straw coloured. (756)
Ripe grains with brown furrows. (269)
Ripe grains Straw coloured. (253)
Ripe grains with brown furrows. (79)
Medium. (600)
Coarse. (156)
Medium. (185)
Coarse. (84)
Medium. (178)
Coarse. (75)
Medium. (56)
Coarse. (23)
Fixed hybrid B. × S. No. 23.

The coarse grained individuals in the F_2 generation of the cross B.×P. possessing dark purple band and auricles and the coarse grained individuals from the cross B.×S. possessing black purple leaf-sheath in the tabulated results above, showed the desired combination, and attention was, therefore, concentrated on these. 69 families (B.×P.) possessing the desired characters were raised in the F_3, and 11 were found to breed true. Of the latter, 7 best families were grown in the F_4 generation, and all of these bred true. Similarly, 42 families (B.×S.) showing the desired combination of characters were grown in the F_3 and 8 bred true. From the latter, 3 best families were raised in the F_4 and all bred true. These then were tested for yield among themselves and against their parents. The testing of yield was carried out by the Latin Square method. The yield in ounces of each strain, repeated 13 times in plots (4′×4′), is noted below the varietal number in the plan below :—

22/1 19½	Par. 20	23 28	15 30¾	30 25½	Bho. 31	24 29½	Sur. 22¾	19 33	22/2 27¾	12 26½	20 28¾	11 29½
Bho. 19½	20 16	19 21	23 18¼	11 19	22/2 18¼	Par. 21½	24 25	30 13¼	22/1 19	15 22½	Sur. 18¼	12 24½
12 25½	22/2 21	Sur. 22	30 25½	Par. 23	24 27¾	22/1 30¼	19 25½	20 27½	11 21¾	23 27	Bho. 29¼	15 32
24 23	30 21¾	12 26	11 27	23 25¾	15 25½	Sur. 21¾	22/1. 27	Bho. 27¾	19 25¼	Par. 24	22/2 24½	20 27¼
19 26½	Sur. 17¼	24 28½	Bho. 28	22/1 27½	30 25½	15 25¾	22/2 23¼	Par. 26	12 25	20 28½	11 28¼	23 28¼
22/2 25¾	24 24	Bho. 25½	Par. 21	Sur. 20½	22/1 27¼	23 26¼	12 24¼	11 19	20 25	19 26½	15 25¼	30 21
Par. 22¾	23 25½	22/1 27	Sur. 20	20 23½	12 23	30 20½	Bho. 21¼	22/2 23¼	15 27	11 24	19 26	24 29¼
20 26½	11 18	30 15½	24 25½	22/2 19½	Par. 21	19 23	15 19¼	12 23½	23 23¾	Sur. 21	22/1 27½	Bho. 29¾
15 21½	Bho. 22¾	11 19	22/2 20¾	12 22¾	19 17½	20 20½	23 26	22/1 24¾	Par. 20½	30 21¼	24 30	Sur. 21½
23 25½	22/1 29	15 16½	20 23	19 18¼	11 24	12 26	Par. 22	Sur. 22½	24 31¼	Bho. 29	30 25½	22/2 21½
11 23¼	19 20¾	Par. 15	12 25½	24 25	20 24¾	Bho. 27¼	30 21¾	15 29	Sur. 27½	22/2 26	23 31½	22/1 31½
30 20¾	12 20¾	20 21	22/1 25¾	15 25¾	Sur. 21¼	22/2 25¾	11 26½	23 29½	Bho. 28½	24 29	Par. 24½	19 22¼
Sur. 16¾	15 24¾	22/2 21½	19 13	Bho. 22	23 30½	11 22½	20 21½	24 26¾	30 20	22/1 22¼	12 24½	Par. 19¼

The following table gives the mean yields, standard deviations and the probable errors of the mean for each of the hybrids and their parents. The method of calculating these constants has been added as an appendix.*

Variety	Mean	Standard Diviation	Probable error of means
B, × P. No. 11	23·21	3·67	0·6877
,, 12.	24·44	1·59	0·298
,, 15.	25·04	4·84	0·9067
,, 19.	22·96	4·85	0·91
,, 20.	24·13	3·61	0·66
,, 22/1.	26·02	3·67	0·6877
,, 22/2.	22·98	2·77	0·5072
B. × S. No. 23.	26·59	3·27	0·6127
,, 24.	26·5	3·15	0·5902
,, 30.	21·36	3·63	0·68
Bhondu	26·26	3·84	0·7194
Parewa	21·58	2·6	0·4872
Surmatia	21·00	2·63	0·4928

Nos. 22 and 12 from the cross B. × P., and No. 23 from the cross B. × S. stood out prominently, and it is worthy of note that these results coincided with those obtained in the field-scale trials as will be seen from the table below :—

Hybrid Number		Average yield per acre (1928 to 1930)
B. × P. No. 11	Grains brown	3265 lbs
B. × P. No. 12	Grains brown	3556 ,,
B. × P. No. 15	Grains with light brown furrows	3591 ,,
B. × P. No. 19	Grains with light brown furrows	3243 ,,
,, 20	Grains with light brown furrows	3539 ,,
,, 22	Grains with light brown furrows	4039 ,,
B. × S. No. 23	Grains with light brown furrows	4336 ,,
,, 24	Grains with light brown furrows	3698 ,,
,, 30	Grains with light brown furrows	3433 ,,

These fixed hybrids show better performance in the field than their parents and with the added advantage of being readily distinguished from the wild rices should find much favour with the cultivator.

Considerable as these achievements have been, there still remains a vast field for further work. The elimination of the weak straw character of most of our rices demands immediate attention. It may be possible to transfer by crossing the strength of straw of certain improved strains of Luchai to our weak strawed but otherwise high-yielding varieties of rice.

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Appendix.

Serial No.	B.×P. No. 11		B.×P. No 12	
	Yield	(Yield)²	Yield	(Yield)²
1	22·50	506·3	24·50	600·3
2	26·50	702·1	20·75	430·7
3	24·00	576·0	26·00	676·0
4	23·25	540·5	25·50	650·1
5	19·00	361·0	22·75	517·6
6	18·00	324·0	23·50	552·4
7	24·00	576·0	23·00	529·0
8	19·00	361·0	24·25	588·0
9	28·25	798·0	25·00	625·0
10	27·00	729·0	26·00	676·0
11	21·75	473·2	25·50	650·1
12	19.00	361·0	24·50	600·3
13	29·50	870·2	26·50	702·1
Total	301·75	7178·3	317·75	7797·6

$$\text{Mean} = \frac{301{\cdot}75}{13} = 23{\cdot}21$$

$$\sigma = \sqrt{\frac{7178{\cdot}3}{13} - (23{\cdot}21)^2}$$

$$= \sqrt{552{\cdot}2 - 538{\cdot}8}$$

$$= \sqrt{13{\cdot}6}$$

$$= 3{\cdot}67.$$

$$\text{P. E. of mean} = \frac{0{\cdot}6745 \times 3{\cdot}67}{\sqrt{13.}}$$

$$= 0{\cdot}6877.$$

$$\text{Mean} = \frac{317{\cdot}75}{13} = 24{\cdot}44$$

$$\sigma = \sqrt{\frac{7797{\cdot}6}{13} - (24{\cdot}44)^2}$$

$$= \sqrt{599{\cdot}81 - 597{\cdot}3}$$

$$= \sqrt{2{\cdot}51}$$

$$= 1{\cdot}59.$$

$$\text{P. E. of mean} = \frac{0{\cdot}6745 \times 1{\cdot}59}{\sqrt{13}}$$

$$= 0{\cdot}298.$$

Serial No.	B.×P. No. 15		B.×P. No. 19	
	Yield	(Yield)²	Yield	(Yield)²
1	24·75	612·7	13·00	169·0
2	25·75	663·1	22·25	495·2
3	16·50	272·3	18·25	333·0
4	29·00	841·0	20·75	430·7
5	21·50	462·2	17·50	306·2
6	19·25	370·5	23·00	529·0
7	27·00	729·0	26·00	676·0
8	25·25	637·1	26·50	702·1
9	25·75	663·1	26·50	702·1
10	25·50	650·1	25·25	637·7
11	32·00	1024·0	25·50	650·1
12	22·50	506·3	21·00	441·0
13	30·75	945·5	33·00	1089·0
Total .	325·50	8377·4	298·50	7161·1

$$\text{Mean} = \frac{325{\cdot}50}{} = 25{\cdot}04.$$

$$\sigma = \sqrt{\frac{8377{\cdot}4}{13} - (25{\cdot}04)^2}$$

$$= \sqrt{644{\cdot}42 - 627{\cdot}0}$$

$$= \sqrt{23{\cdot}41}$$

$$= 4{\cdot}84.$$

$$\text{P. E. of mean} = \frac{0{\cdot}6745 \times 4{\cdot}84}{\sqrt{13}}$$

$$= 0{\cdot}9067.$$

$$\text{Mean} = \frac{298{\cdot}50}{13} = 22{\cdot}96.$$

$$\sigma = \sqrt{\frac{7161}{13} - (22{\cdot}96)^2}$$

$$= \sqrt{550{\cdot}8 - 527{\cdot}2}$$

$$= \sqrt{23{\cdot}6}$$

$$= 4{\cdot}85.$$

$$\text{P. E. of mean} = \frac{0{\cdot}6745 \times 4{\cdot}85}{\sqrt{13}}$$

$$= 0{\cdot}91.$$

Serial No.	B.×P. No. 20		B.×P. No. 22/1	
	Yield	(Yield)²	Yield	(Yield)²
1	21·50	462·2	22·25	495·2
2	21·00	441·0	25·75	663·1
3	23·00	529·0	29·00	841·0
4	24·75	612·7	31·50	992·0
5	20·50	420·3	24·75	612·7
6	26·50	702·1	27·50	756·1
7	23·50	552·4	27·00	729·0
8	25·00	625·0	27·25	742·7
9	28·50	812·1	27·50	756·1
10	27·25	742·7	27·00	729·0
11	27·50	656·1	30·25	914·9
12	16·00	256·0	19·00	361·0
13	28·75	826·8	19·50	380·0
Total .	313·75	7738·4	338·25	8973·0

$$\text{Mean} = \frac{313\cdot75}{13} = 24\cdot13.$$

$$\sigma = \sqrt{\frac{7738\cdot4}{13} - (24\cdot13)^2}$$

$$= \sqrt{595\cdot3 - 582\cdot25}$$

$$= \sqrt{13\cdot05}$$

$$= 3\cdot61.$$

$$\text{P. E. of mean} = \frac{0\cdot6745 \times 3\cdot61}{\sqrt{13}}$$

$$= 0\cdot66.$$

$$\text{Mean} = \frac{338\cdot25}{13} = 26\cdot02.$$

$$\sigma = \sqrt{\frac{8973\cdot0}{13} - (26\cdot02)^2}$$

$$= \sqrt{690\cdot23 - 677\cdot04}$$

$$= \sqrt{13\cdot53}$$

$$= 3\cdot67.$$

$$\text{P. E. of mean} = \frac{0\cdot6745 \times 3\cdot67}{\sqrt{13}}$$

$$= 0\cdot6877.$$

Serial No.	B. × P. No. 22/2		B. × S. No. 23	
	Yield	(Yield)^2	Yield	(Yield)^2
1	21·50	462·2	30·50	930·3
2	25·75	663·1	29·50	870·2
3	21·50	462·2	25·50	650·1
4	26·00	476·0	31·50	992·2
5	20·75	430·7	26·00	676·0
6	19·50	380·2	23·75	563·9
7	23·25	540·5	25·50	650·1
8	25·75	663·1	26·25	689·0
9	23·25	540·5	28·25	798·0
10	24·50	600·3	25·75	663·1
11	21·00	441·0	27·00	729·0
12	18·25	333·0	18·25	333·0
13	27·75	770·2	28·00	784·0
Total .	298·75	6963·0	345·75	9328·9

$$\text{Mean} = \frac{298{\cdot}75}{13} = 22{\cdot}98.$$

$$\sigma = \sqrt{\frac{6963{\cdot}0}{13} - (22{\cdot}98)^2}$$

$$= \sqrt{535{\cdot}6 - 527{\cdot}9}$$

$$= \sqrt{7{\cdot}70}$$

$$= 2{\cdot}77.$$

$$\text{P. E. of mean} = \frac{0{\cdot}6745 \times 2{\cdot}77}{\sqrt{13}}$$

$$= 0{\cdot}5072.$$

$$\text{Mean} = \frac{345{\cdot}75}{13} = 26{\cdot}59.$$

$$\sigma = \sqrt{\frac{9328{\cdot}9}{13} - (26{\cdot}59)^2}$$

$$= \sqrt{717{\cdot}60 - 706{\cdot}9}$$

$$= \sqrt{10{\cdot}7}$$

$$= 3{\cdot}27.$$

$$\text{P. E. of mean} = \frac{0{\cdot}6745 \times 3{\cdot}27}{\sqrt{13}}$$

$$= 0{\cdot}6127.$$

Serial No.	B.×S. No. 24		B.×S. No. 30	
	Yield	(Yield)²	Yield	(Yield)²
1	26·75	715·5	20·00	400·0
2	29·00	841·0	20·75	430·7
3	31·25	976·8	25·50	650·1
4	25·00	625·0	21·75	473·2
5	30·00	900·0	21·25	451·4
6	25·50	650·1	15·50	240·2
7	29·25	855·5	20·50	420·3
8	24·00	576·0	21·00	441·0
9	28·50	812·1	25·50	650·1
10	23·00	529·0	21·75	473·2
11	27·75	770·2	25·50	650·1
12	25·00	625·0	13·25	175·6
13	19·50	380·2	25·50	650·1
Total .	344·50	9256·4	277·75	6106·0

$$\text{Mean} = \frac{344{\cdot}50}{13} = 26{\cdot}5.$$

$$\sigma = \sqrt{\frac{9256{\cdot}4}{13} - 26{\cdot}5}$$

$$= \sqrt{712{\cdot}03 - 702{\cdot}1}$$

$$= \sqrt{5{\cdot}93}$$

$$= 3{\cdot}15.$$

$$\text{P. E. of mean} = \frac{0{\cdot}6745 \times 3{\cdot}15}{\sqrt{13}}$$

$$= 0{\cdot}5902.$$

$$\text{Mean} = \frac{277{\cdot}75}{13} = 21{\cdot}36.$$

$$\sigma = \sqrt{\frac{6106{\cdot}0}{13} - (21{\cdot}36)^2}$$

$$= \sqrt{469{\cdot}7 - 456{\cdot}2}$$

$$= \sqrt{13{\cdot}5}$$

$$= 3{\cdot}63.$$

$$\text{P. E. of mean} = \frac{0{\cdot}6745 \times 3{\cdot}63}{\sqrt{13}}$$

$$= 0{\cdot}68.$$

G

Serial No.	Bhondu		Parewa	
	Yield	(Yield)^2	Yield	(Yield)^2
1	22·00	484·0	19·25	370·5
2	23·50	812·1	24·50	600·3
3	29·00	841·0	22·00	484·0
4	27·75	742·7	15·00	225·0
5	22·75	517·6	20·50	420·3
6	29·75	885·1	21·00	441·0
7	21·25	473·2	22·75	517·6
8	25·50	650·1	21·00	441·0
9	28·00	784·0	26·00	676·0
10	27·75	770·2	24·00	576·0
11	29·25	855·5	23·00	529·0
12	19·50	380·2	21·50	462·2
13	31·00	961·0	20·00	400·0
Total	341·50	9156·7	280·50	6142·9

Mean $= \frac{341·50}{13} = 26·26.$

$\sigma = \sqrt{\frac{9156·7}{13} - (26·26)^2}$

$= \sqrt{704·36 - 689·6}$

$= \sqrt{14·76}.$

$= 3·84$

P. E. of mean $= \frac{0·6745 \times 3·84}{\sqrt{13}}.$

$= 0·7194.$

Mean $= \frac{280·50}{13} = 21·58.$

$\sigma = \sqrt{\frac{6142·9}{13} - (21·58)^2}$

$= \sqrt{472·5 - 465·8}$

$= \sqrt{6·7}$

$= 2·6.$

P. E. of mean $= \frac{0·6745 \times 2·6}{\sqrt{13}}$

$= 0·4872.$

Serial No.	Surmatia	
	Yield	(Yield)^2
1	16·75	280·5
2	21·25	451·4
3	22·50	506·3
4	27·50	756·1
5	21·50	462·2
6	21·00	441·0
7	20·00	400·0
8	20·50	420·4
9	17·25	297·6
10	21·75	473·2
11	22·00	484·0
12	18·25	333·0
13	22·75	517·6
Total	273·00	5823·3

$$\text{Mean} = \frac{273\cdot00}{13} = 21\cdot00.$$

$$\sigma = \sqrt{\frac{5823\cdot3}{13} - (21)^2}$$

$$= \sqrt{447\cdot9 - 441}$$

$$= \sqrt{6\cdot9}$$

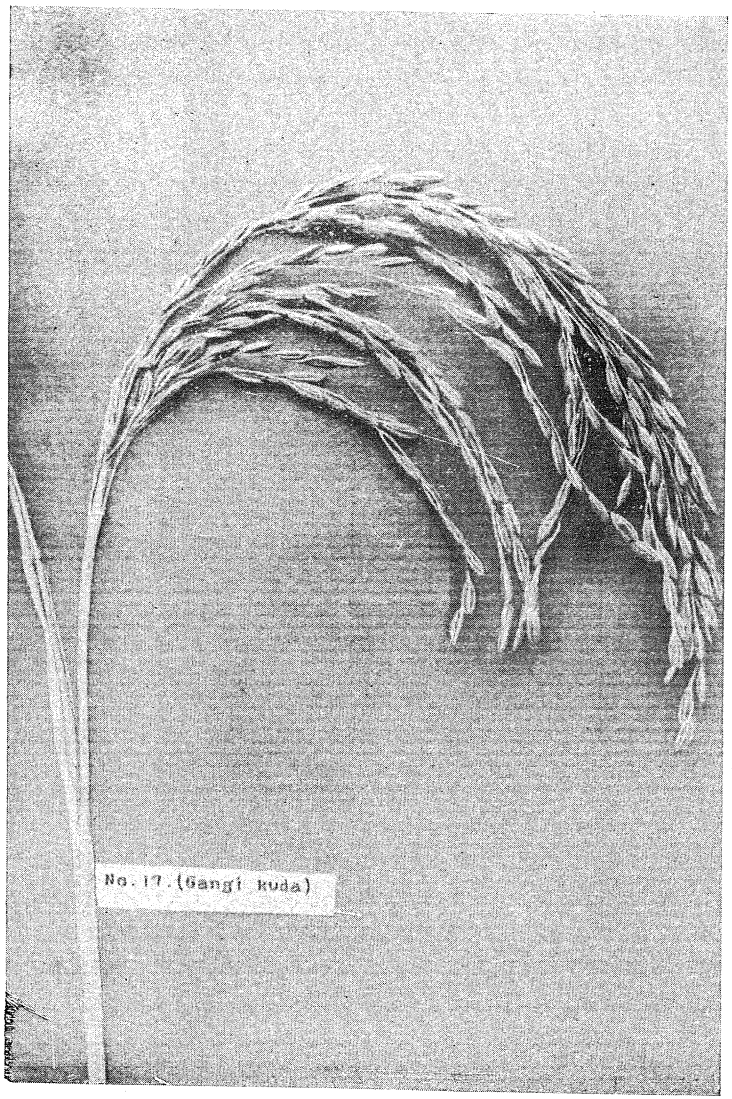
$$= 2\cdot63$$

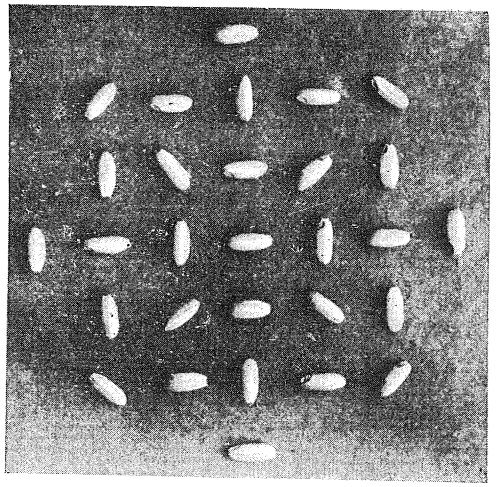
$$\text{P. E. of mean} = \frac{0\cdot6745 \times 2\cdot63}{\sqrt{13}}$$

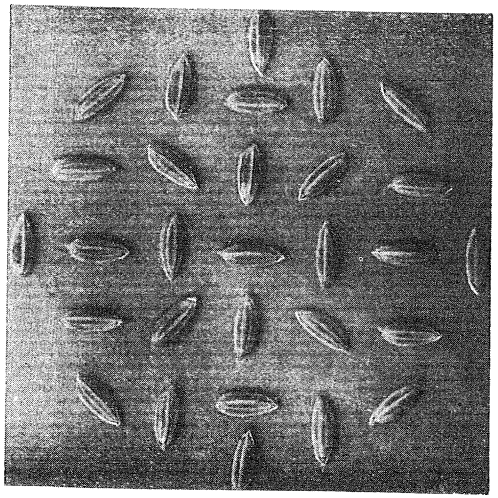
$$= 0\cdot4928.$$

Calculation of statistical significance.

Variety	Mean	P. E. of mean	Difference of mean	P. E. of difference of mean	Dif. of mean ÷ P. E. of dif. of mean	Remarks
B. × P. No. 11 .	23·21	0·69	3·05	0·99	3·09	Insignificant.
Bhondu . .	26·26	0·72				
B. × P. No. 11 .	23·21	0·69	1·63	0·84	1·9	Do.
Parewa . .	21·58	0·49				
B. × P. No. 12 .	24·44	0·29	1·82	0·78	2·33	Do.
Bhondu . .	26·26	0·72				
B. × P. No. 12 .	24·44	0·29	2·86	0·57	5·0	Significant.
Parewa . .	21·58	0·49				
B. × P. No. 15 .	25·04	0·90	1·22	1·15	1·0	Insignificant.
Bhondu . .	26·26	0·72				
B. × P. No. 15 .	25·04	0·90	3·46	1·02	3·3	Significant.
Parewa . .	21·58	0·49				
B. × P. No. 19 .	22·96	0·91	3·30	1·34	2·4	Insignificant.
Bhondu . .	26·26	0·72				
B. × P. No. 19 .	22·96	0·91	1·38	1·03	1·3	Do.
Parewa . .	21·58	0·42				
B. × P. No. 20 .	24·13	0·66	2·13	0·97	2·2	Do.
Bhondu . .	26·26	0·72				
B. × P. No. 20 .	24·13	0·66	2 55	0 82	3·11	Do.
Parewa . .	21·58	0·49				
B. × P. No. 22-1	26·02	0·68	0·24	0·99	0·24	Do.
Bhondu . .	26·26	0·72				
B. × P. No. 22-1	26·02	0·68	4·44	0·84	5·3	Significant.
Parewa . .	21·58	0·49				

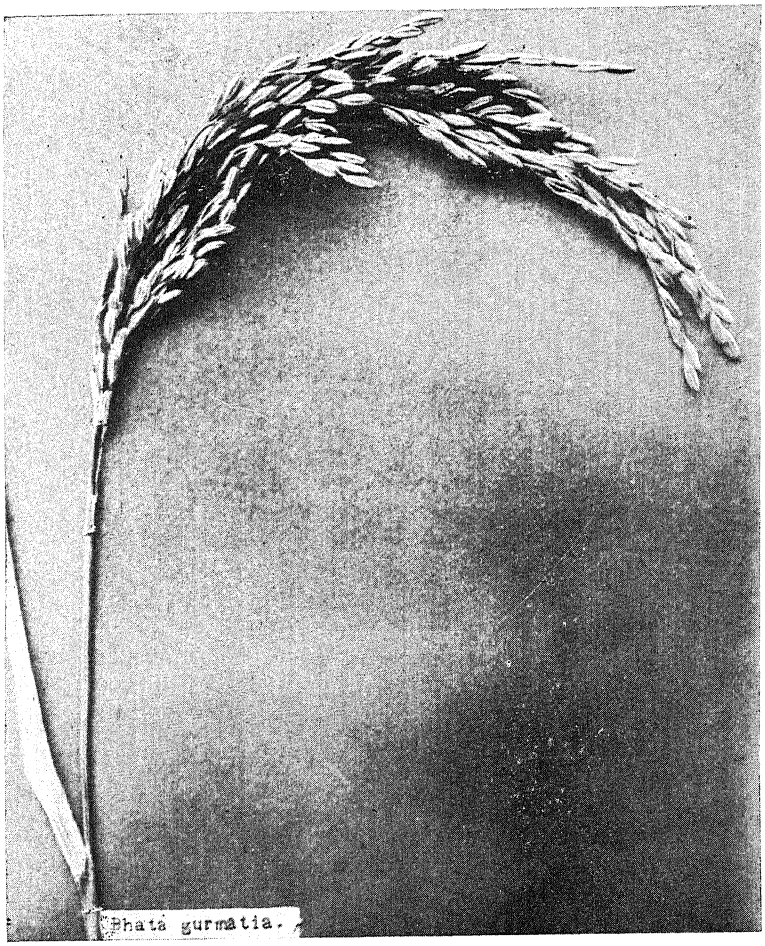


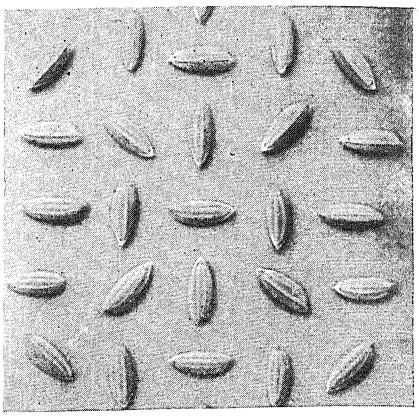




E. B. 17. Selection from Gangi Kuda.

PLATE XX.





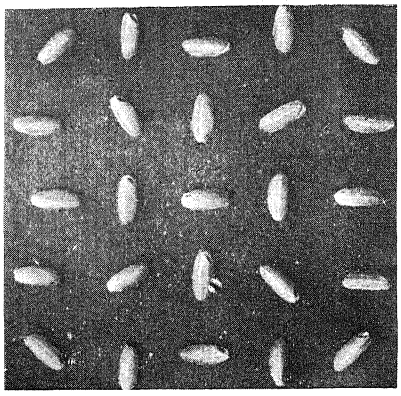
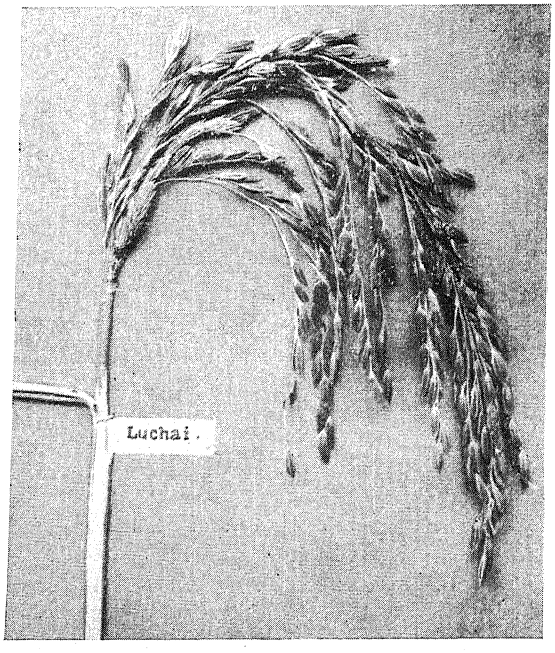
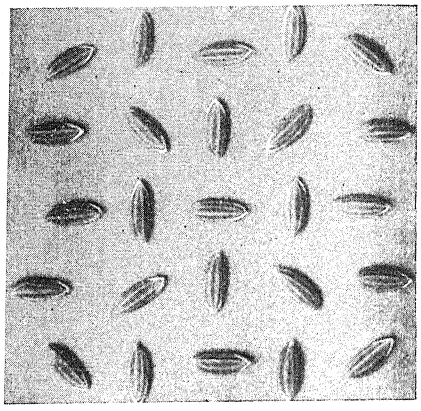
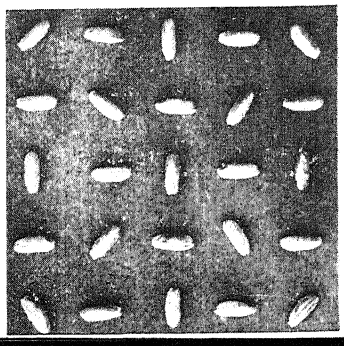


Fig. 1. Bnata gurmatia No. 9.







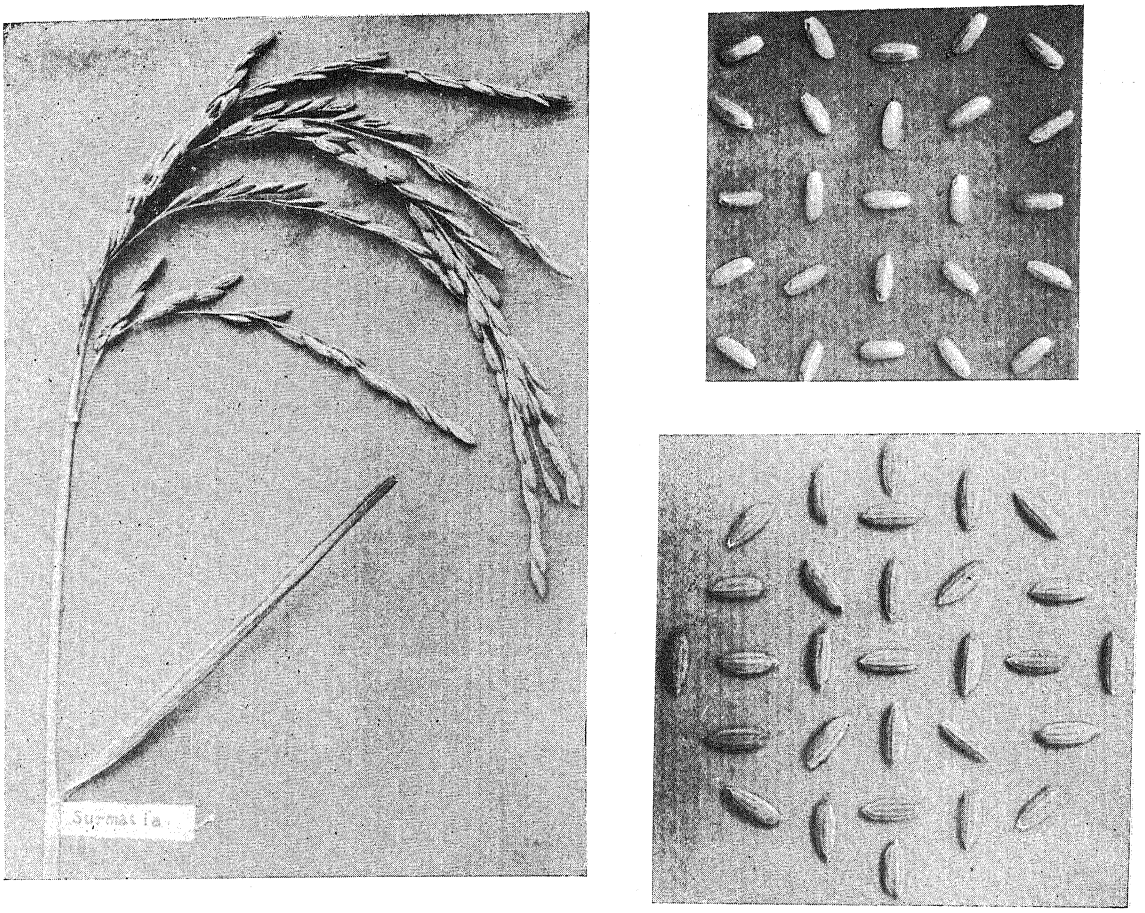


Fig. 1. Surmatia No. 11.

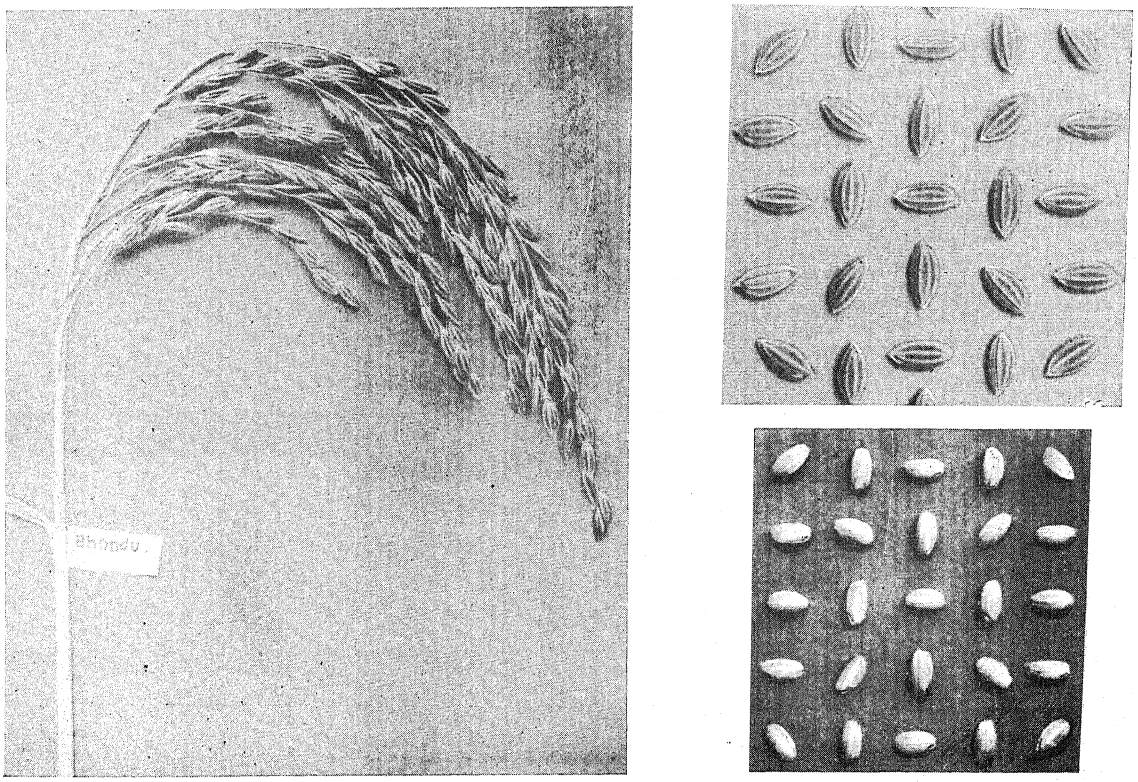
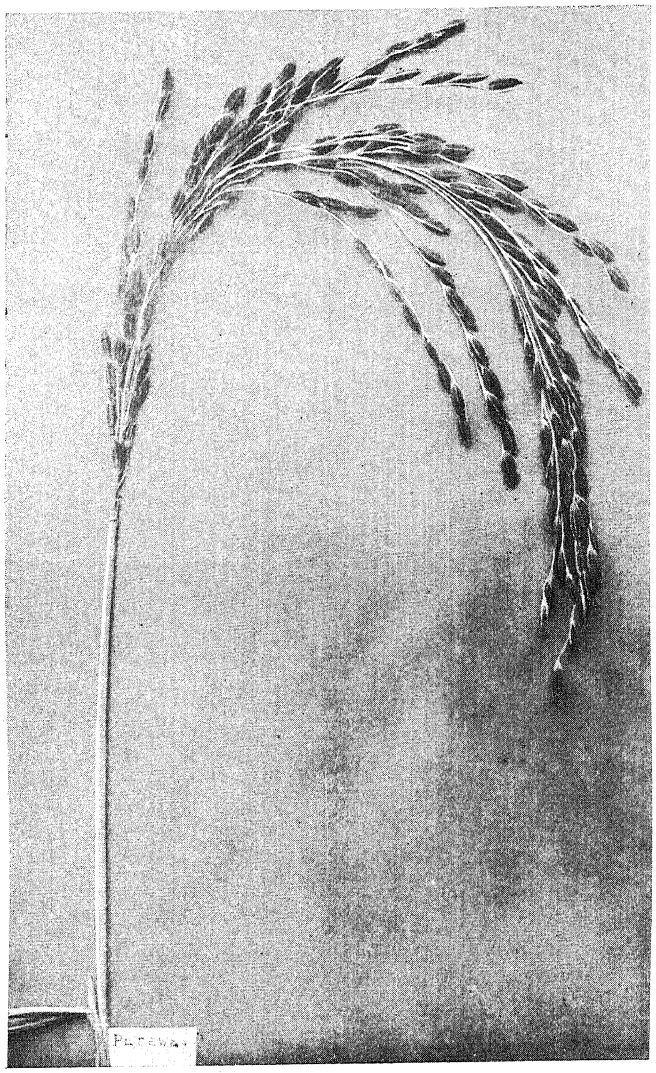
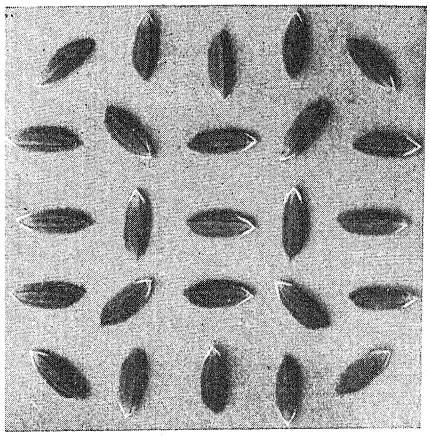


PLATE XXIII.





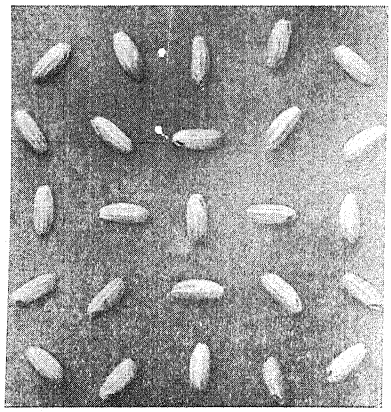


Fig. 1. Parewa No. 22.

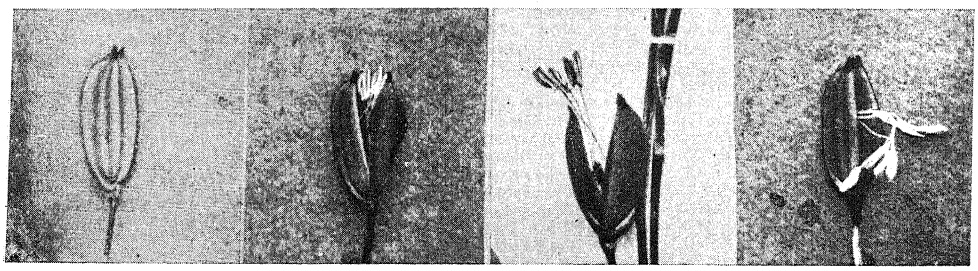
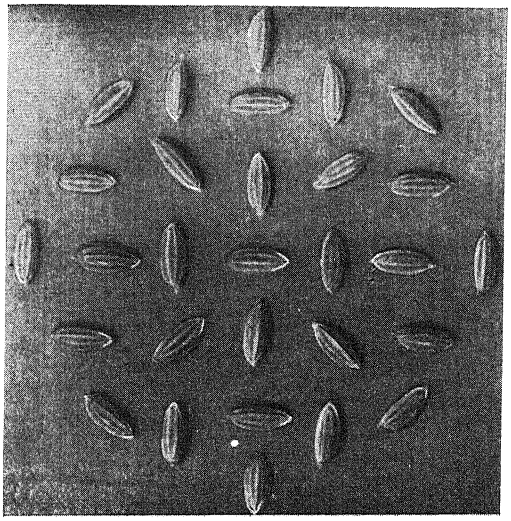
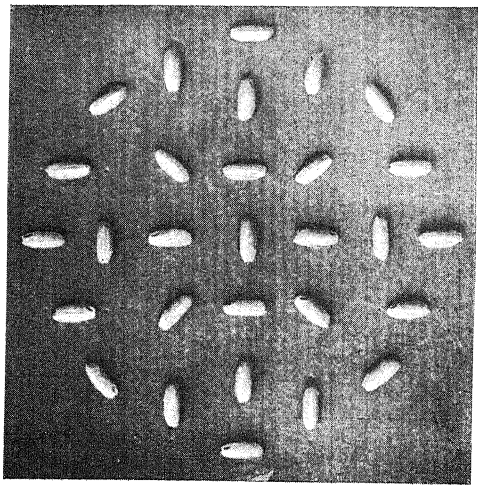
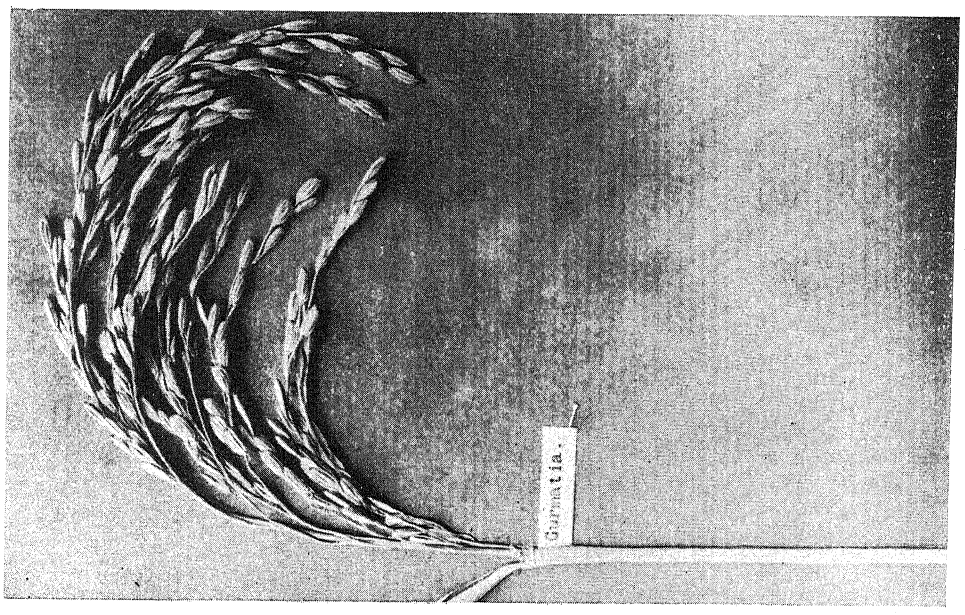


Fig. 2. Showing opening of flower and pollination.

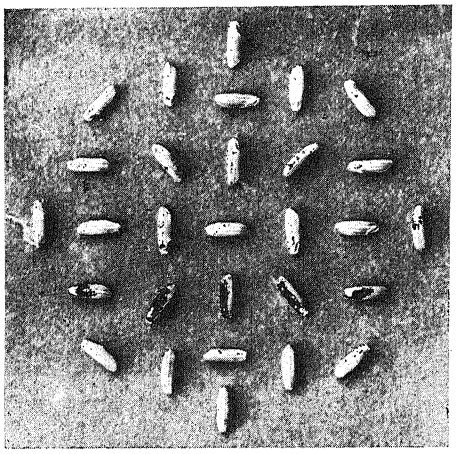


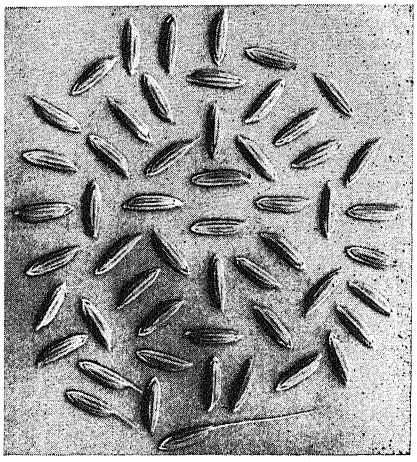


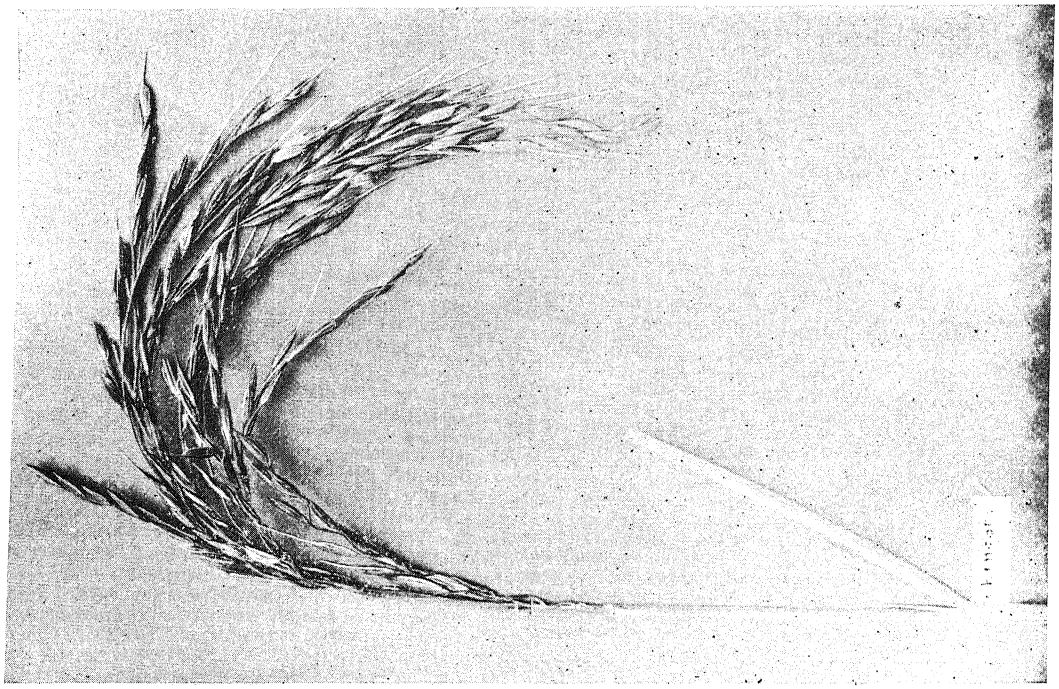


Gurmatia No. 17.

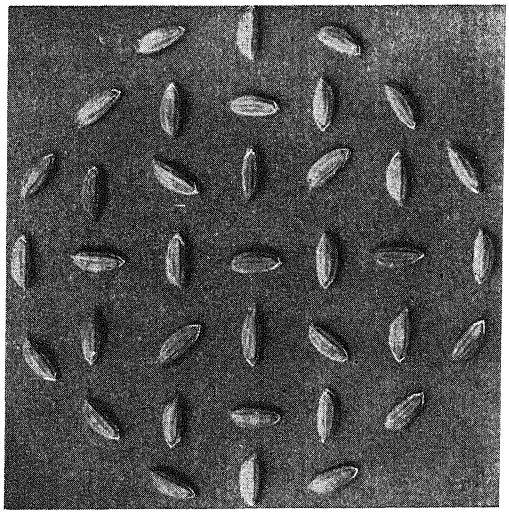
PLATE XXV.

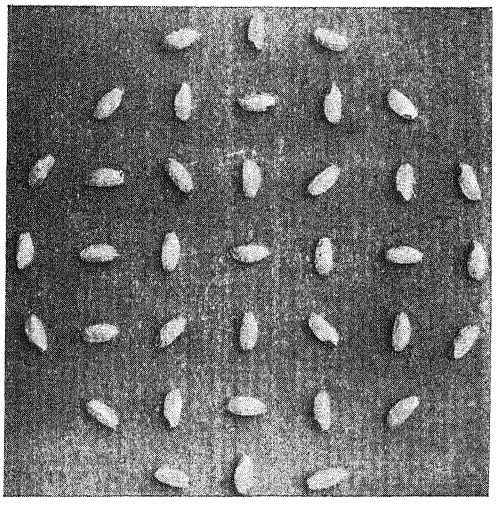


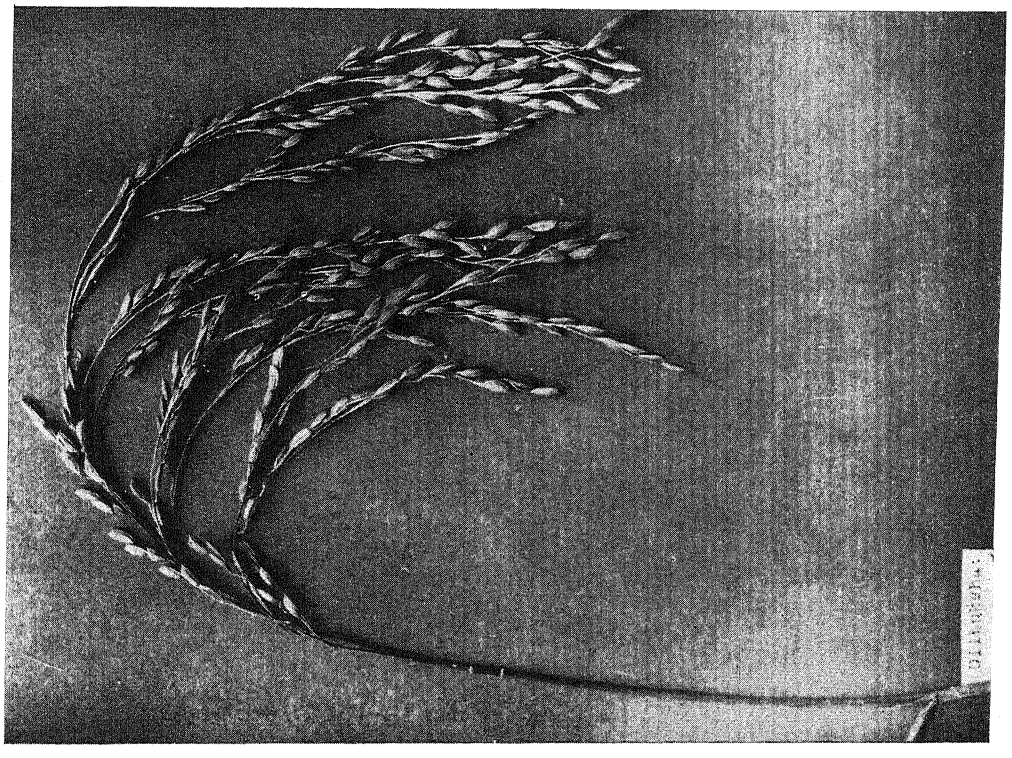




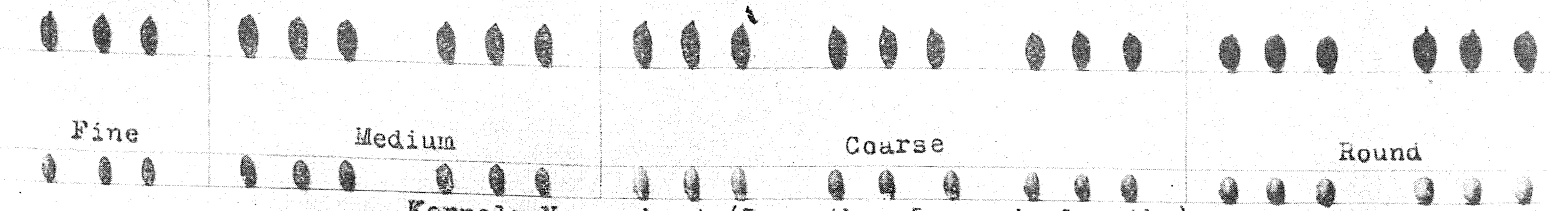
Chinoor No. 21.





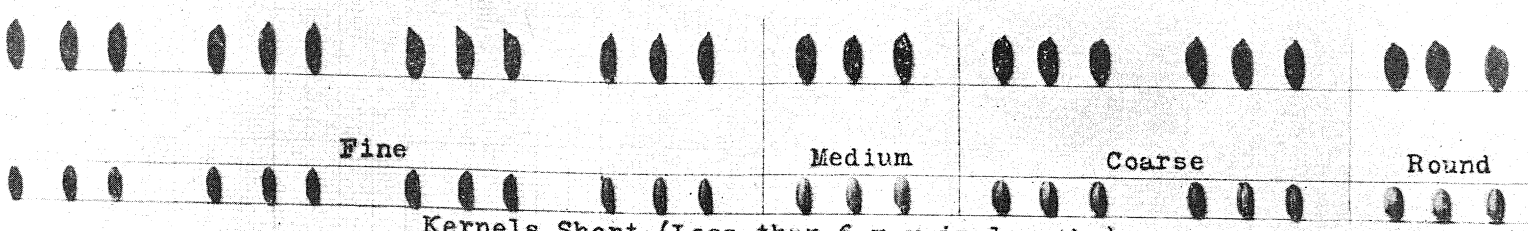


Dilbuksha No. 35.



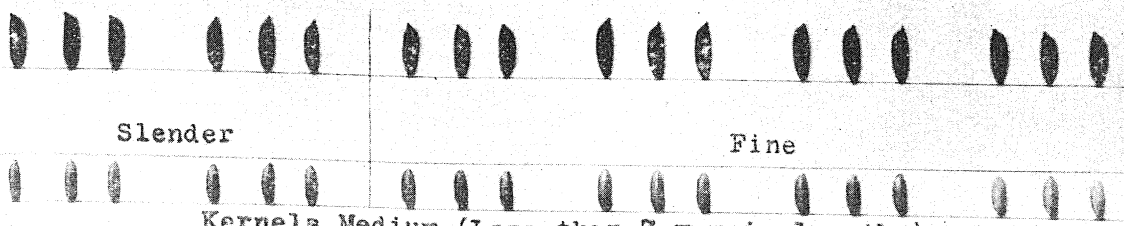
Kernels Very short.(Less than 5 m.m.in length.)

Krishna bhog Padam phul Kubrimohar Dilbuksha Rani kajar Harad gundi Donger manki Maknuja



Kernels Short.(Less than 6 m.m.in length.)

Mohan bhog Bagh muchh Kubri mohar China kapur Jhurai Badri phal Hansa Makka



Kernels Medium.(Less than 7 m.m.in length.)

Pithadi Basmoti Chhitrakot Basmatia Banspatri Luchai

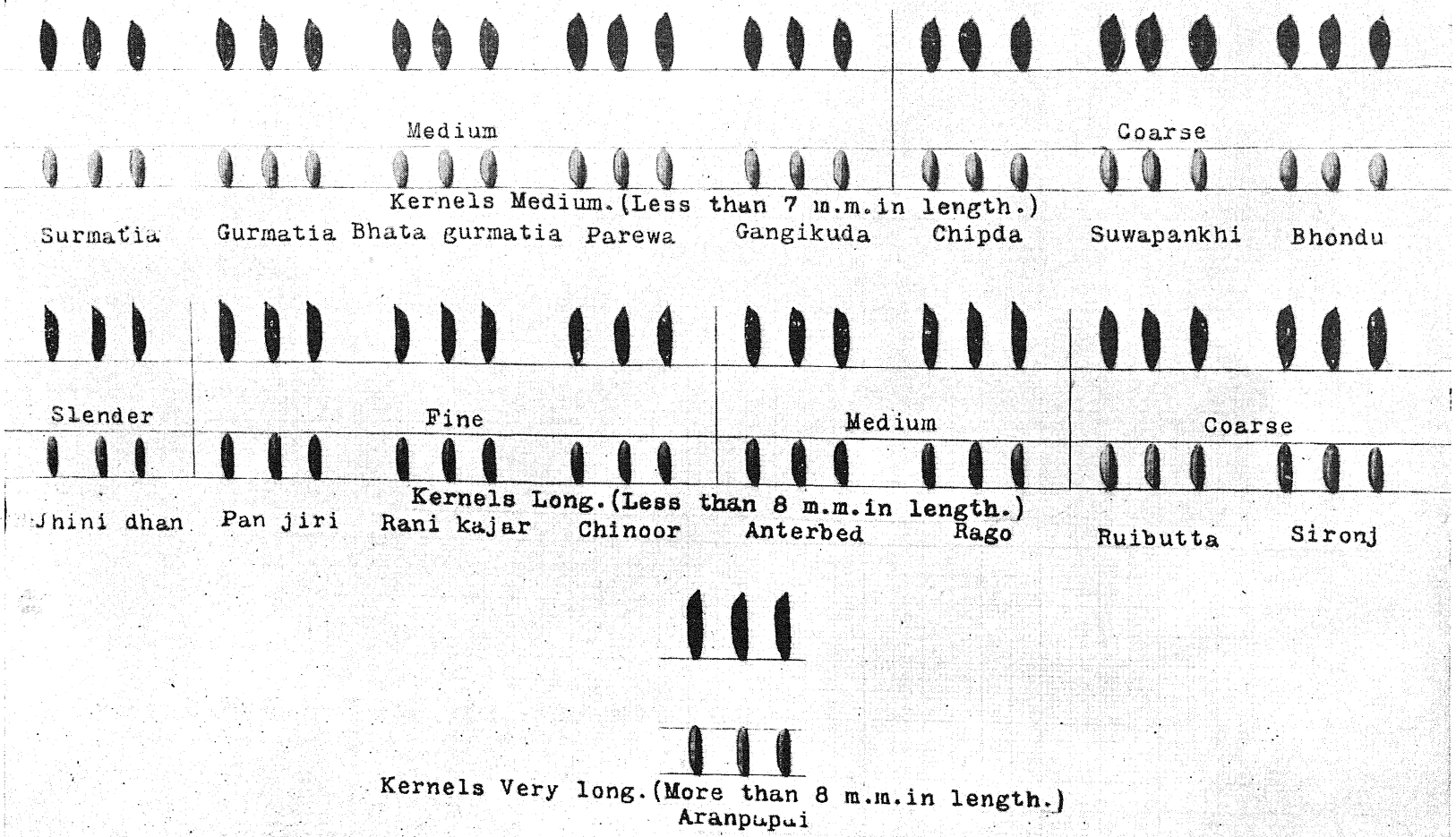
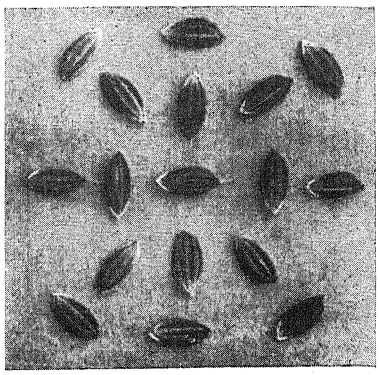


Fig.10. Grains and kernels of some of our rices classified.

PLATE XXVII.

PLATE XXVIII.



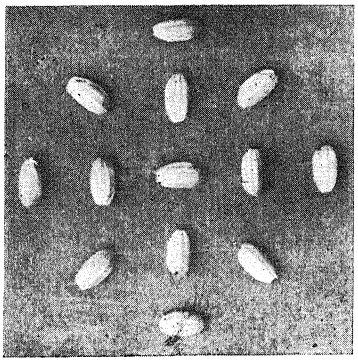
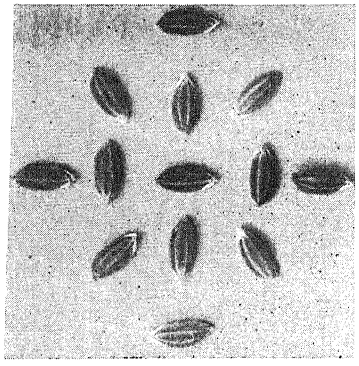


Fig. 2. Fixed Hybrid B. × P. No. 22



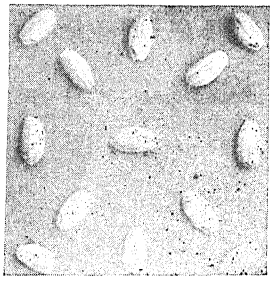
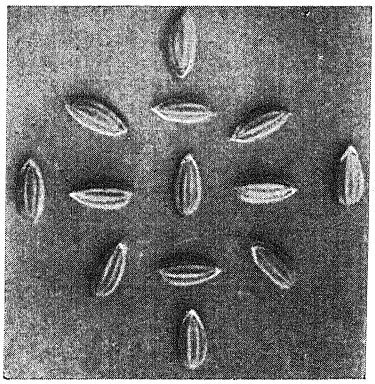
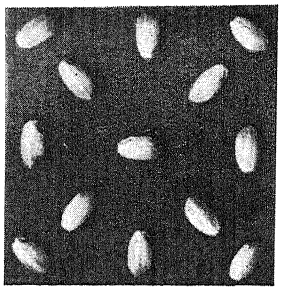
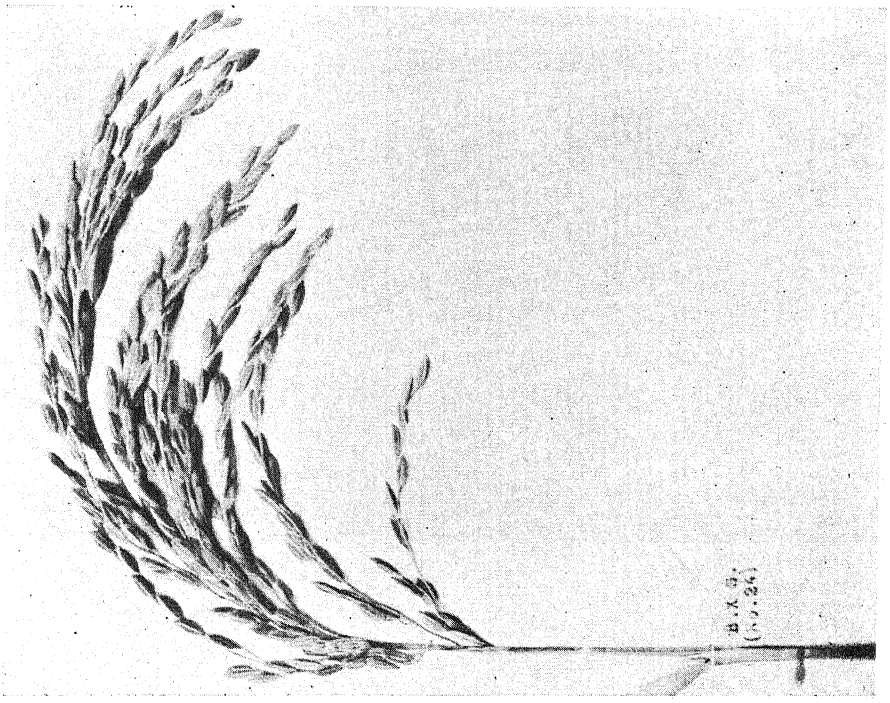


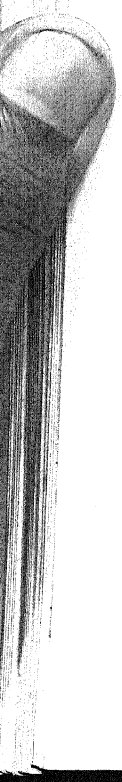
Fig. 1. Fixed Hybrid B. × P. No. 12.







Fixed Hybrid B. × S. No. 23.



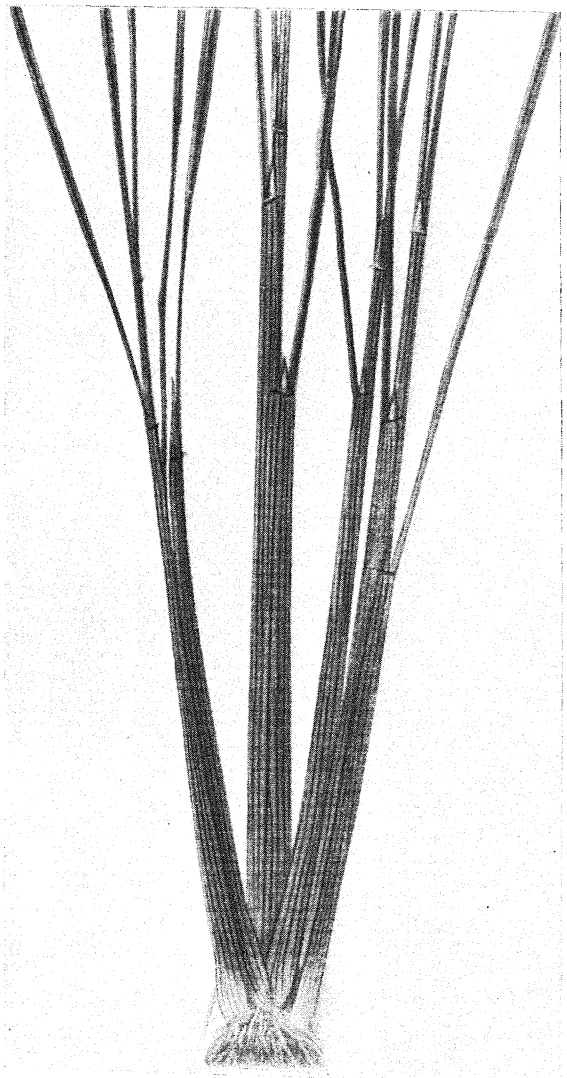


Fig. 1. Dilbuksha No. 35.

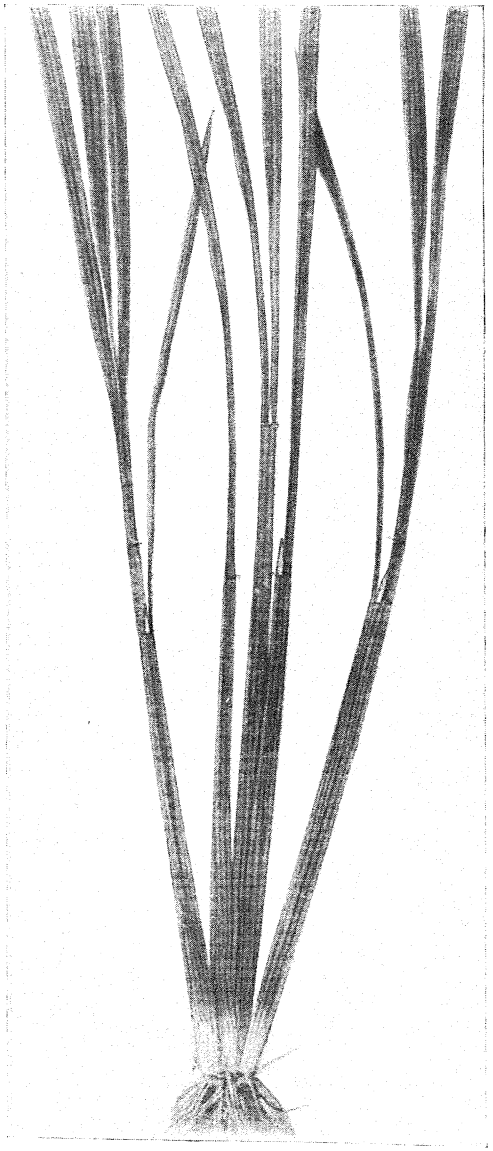


Fig. 2. Chinoor No. 21.

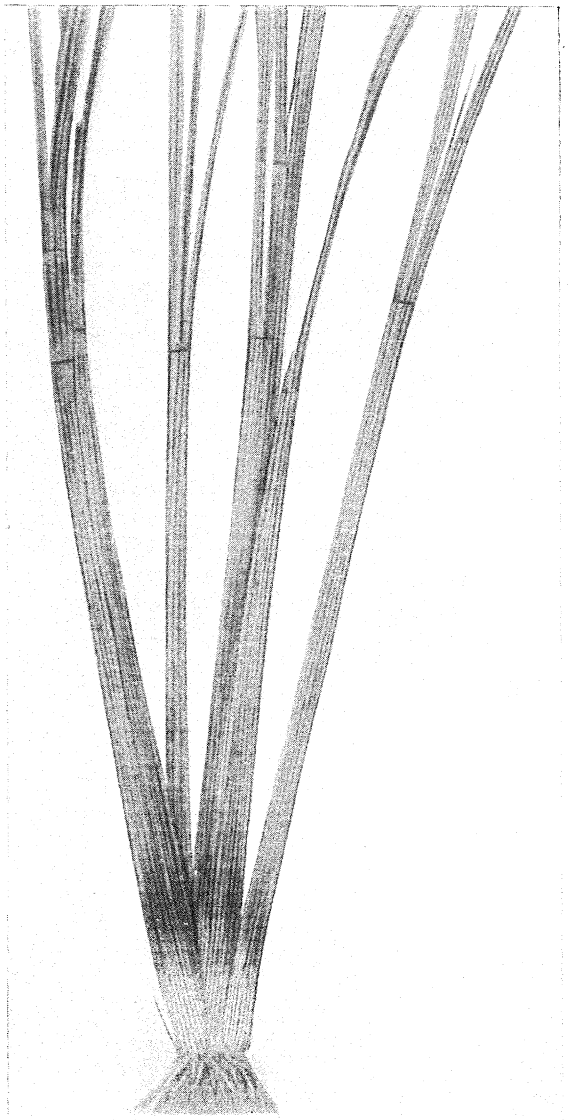


Fig. 3. E. B. 17. Selection from Gangi Kuda.

PLATE XXX.

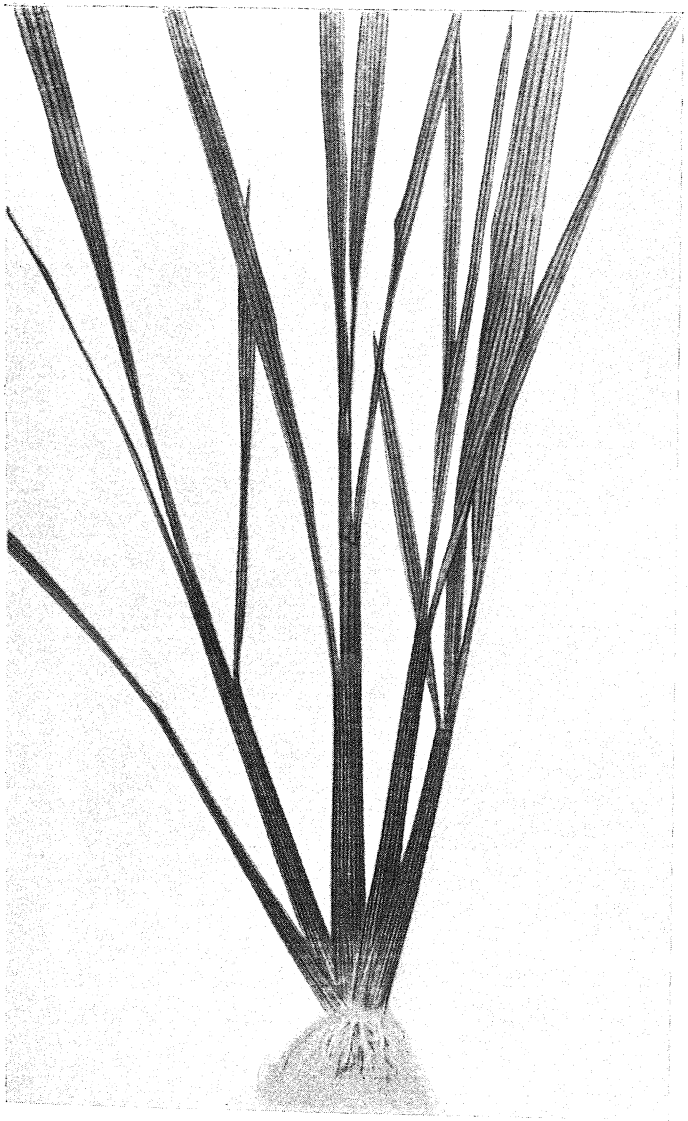


Fig. 1. Gurmatia No. 17.

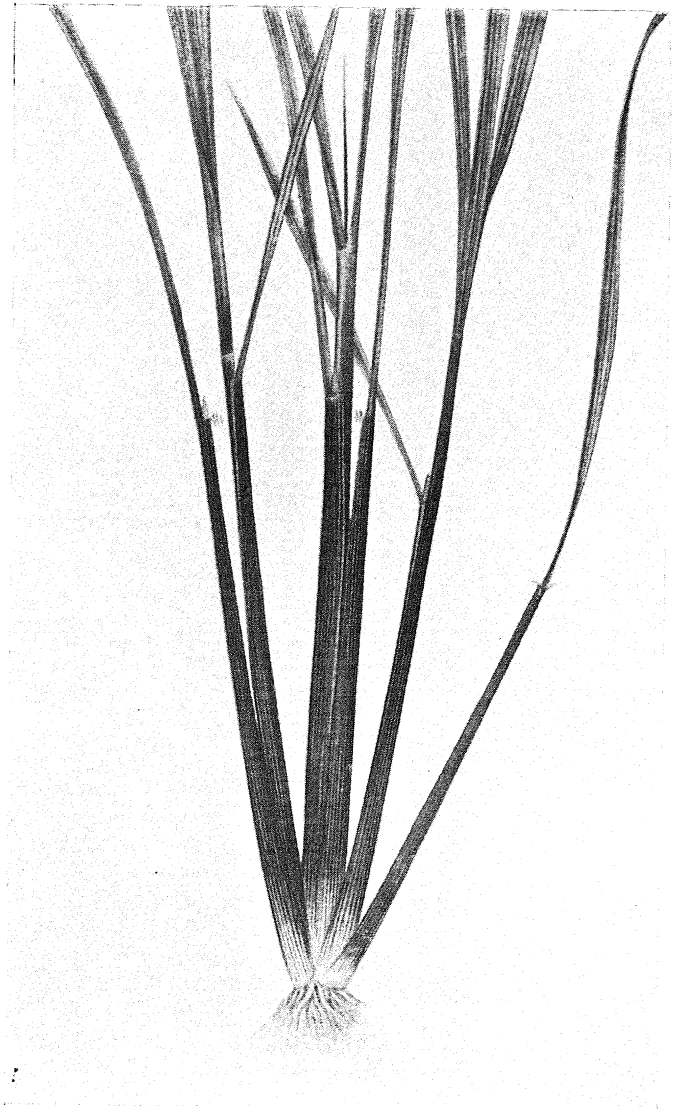
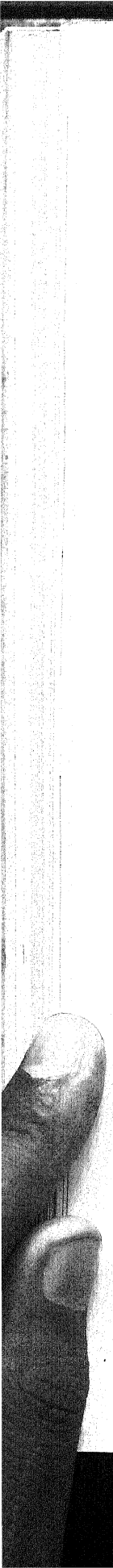


Fig. 2. Fixed Hybrid B.×S. No. 23.

PLATE XXXI.



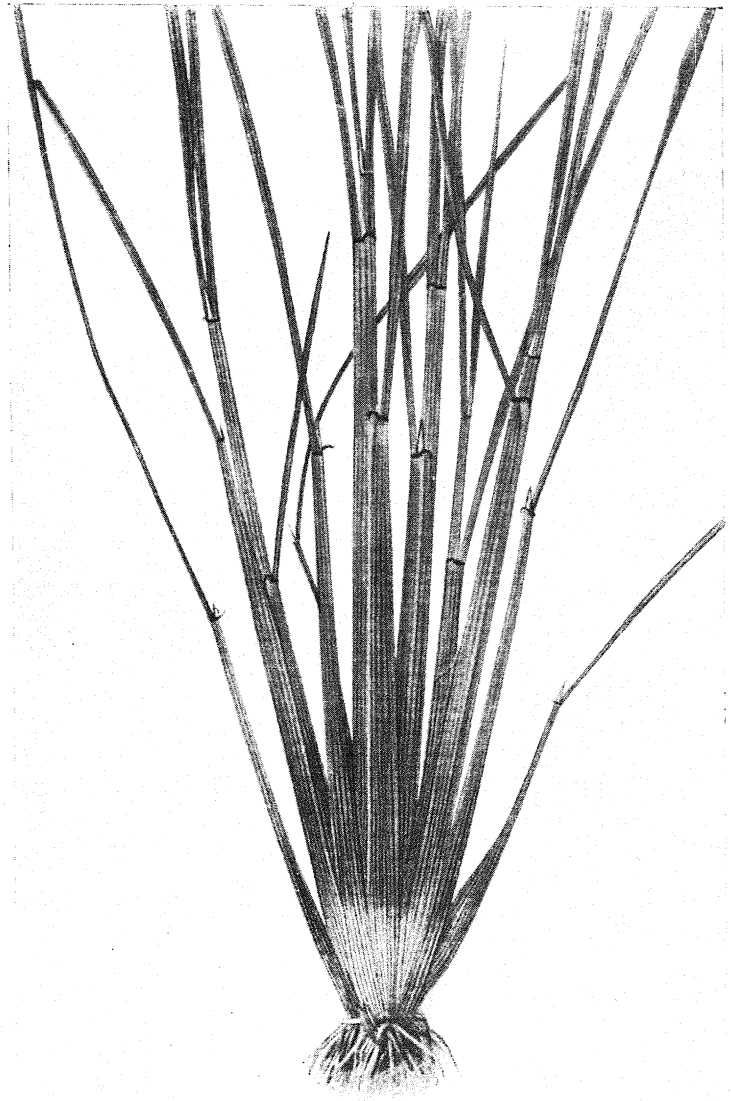


Fig. 1. Fixed Hybrid B.×P. No. 22.

Fig. 2. Fixed Hybrid B.×P. No. 22.

Fig. 3. Fixed Hybrid B.×P. No. 12.

Fig. 4. Fixed Hybrid B.×S. No. 23.

PLATE XXXII.

Calculation of statistical significance—contd.

Variety	Mean	P. E. of mean	Difference of mean	P. E. of difference of mean	Dif. of mean ÷ P. E. of dif. of mean	Remarks
B. × P. No. 22-2	22·98	0·50	3·28	0·88	3·8	Significant.
Bhondu . .	26·26	0·72				
B. × P. No. 22-2	22·98	0·50	1·40	0·70	2·0	Insignificant.
Parewa . .	21·58	0·49				
B. × S. No. 23 .	26·59	0·61	0·33	0·94	0·3	Do.
Bhondu . .	26·26	0·72				
B. × S. No. 23 .	26·59	0·61	5·59	0·78	7·3	Significant.
Surmatia . .	21·00	0·49				
B. × S. No. 24 .	26·50	0·59	0·24	0·93	0·26	Insignificant.
Bhondu . .	26·26	0·72				
B. × S. No. 24 .	26·50	0·59	5·50	0·77	7·1	Significant.
Surmatia . .	21·00	0·49				
B. × S. No. 30 .	21·36	0·68	4·90	0·99	5·0	Do.
Bhondu . .	26·26	0·72				
B. × S. No. 30 .	21·36	0·68	0·36	0·84	0·43	Insignificant.
Surmatia . .	21·00	0·49				

POSSIBLE LOSSES OF FERTILIZING CONSTITUENTS IN THE MANURING OF PADDY.

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(Received for publication on the 3rd February, 1931.)

(With three graphs.)

INTRODUCTORY.

Certain recent manuring experiments on paddy at Mudon and Akyab suggested a lack of response to soluble ammonium phosphate manures, such as Leunaphos and Diammonphos, although these gave excellent results at other places in Burma. This ineffectiveness may be expected to be due to one or other of the following causes :—

A. The fertilizer is unsuitable to the crop or soil or both.

B. Reduction of ammonia to nitrogen and loss as gas.

C. Rapid loss by percolation into drainage and seepage water.

D. Loss by erosion. Fertilizer may be carried away either in suspension or in true solution.

A complete survey of the above possible causes of loss was not attempted, the main object being to discover if intrinsic differences in soil caused the observed failures. At both Mudon and Akyab the rainfall is exceedingly heavy, and it is not possible to drain off the standing water before applying the manure and subsequently well harrowing in as is usual in most districts in Burma. As regards this point, it was actually found at Hmawbi that whereas excellent response to Leunaphos and Diammonphos is obtained when the manures are applied to the land after first running off the standing water, sowing the manures in the standing water gave a significantly smaller increase. This fact required explanation, and was kept in view in the subsequent laboratory investigation. The absorption of ammonia and phosphate by soil has attracted much attention since the chemical ideas evolved by Way 80 years ago. The application of Freundlich's absorption curves and equations led to consideration of the absorption of phosphate and other substances as physical absorptions [Prescott, 1916 ; Harrison and Das, 1921]. This physical theory has been criticised by Fisher [1921] and Comber [1924]. The influence of the pH at which absorption occurs has been extensively investigated in America [Starkey and Gordan, 1922 ; Fraps, 1922 ; Roszmann, 1927 ; Teakle, 1928 ; Miller, 1928], as a

result of which it appears that in acid soils phosphate is combined with Fe and Al, and in neutral or calcareous soils with Ca. Some phosphate is probably in organic combination, however, [Teakle, 1928; Auten, 1923]. At the present time it is generally considered that most of the phenomena involving soil acidity, base exchange and absorption may be explained as chemical reactions subject to the law of mass action, with the important proviso that one of the reactive ions forms part of a colloidal phase. Thus when soil is treated with a neutral salt solution, there is an interchange of cations between the solution and the reacting colloids in chemical proportions. At equilibrium the amount of ions absorbed and replaced is an exponential function of the equilibrium concentration of the replacing ion in solution. Hence the reaction follows the general type of Freundlich's absorption curves and equations.

Preliminary Experiments.

A. Since both Leunaphos and Diammonphos give excellent results in most localities, their failure in others does not necessarily mean that they are unsuitable there, since the failures may be due to the method of application of the manures.

B. A rough test to discover if the ammonia in such manures may be reduced to nitrogen was carried out as follows. Bottles containing 1,000 grm. paddy soils and 2,000 c.c. water were allowed to stand for nine weeks. To certain of the soils was added Leunaphos at the rate of 0·1 grm. nitrogen per 1,000 grm. soil. The evolution of gas was noted. The maximum evolution was 10·00 c.c. in the manured bottles, and the average of the controls was 3·0 c.c. As it happened, the gas could not be analysed, but even assuming that the difference were nitrogen, the loss is not sufficient to account for the failure of Leunaphos with such a soil. It should, of course, be remembered that the evolution of gas from paddy soils depends very largely upon whether the soil is cropped or not, and the greater part of the nitrogen begins to be lost at about flowering time [Harrison and Subramania Aiyer, 1916], whereas in uncropped soils the evolution of nitrogen is fairly uniform. The experiment was therefore very inadequate, but it served to answer the question as to whether application of manures with first ploughing instead of at transplanting was allowable or not. Obviously there is no objection, provided that there is no loss by erosion or percolation from the field.

C. Paddy soils from Akyab, Mudon, Mandalay and Hmawbi were taken, 1,000 grm. of each soil being placed in inverted Winchester quart bottles, the bottom of each of which had been removed, arrangements having been made to collect the percolate through the necks of the bottles. The soils were worked up with distilled water before they were put in the bottles, and after introduction a constant head of 3″ distilled water was maintained until the percolate was clear in all cases. At this

point Leunaphos equivalent to 0·1 grm. nitrogen was added to all the bottles and the percolation waters collected separately. The percolate was analysed for each 4″ of drainage in the case of Akyab and Mandalay soils, but drainage was so slow in the case of the other soils that only one analysis could be done. It was found that the nitrogen content in the successive percolates from the Akyab and Mandalay soils diminished, but only the totals for the whole period are given below in Table I.

TABLE I.

Composition of drainage water from manured paddy soils (grams per litre).

Soil	Percolate collected	Collected in	Drainage equivalent to	Composition of percolate per litre				
				NH_4 Salts	Albuminoid NH_2	Nitrate N	Nitrite N	P_2O_5
Akyab . .	3 litres .	23 days	12″	0·00212	0·00187	*nil*	0·0000062	*nil*
Mandalay .	3 litres .	30 days	12″	0·00023	0·00039	*nil*	*nil*	*nil*
Hmawbi . .	250 c. c. .	5 weeks	1″	0·00009	0·00453	0·00010	0·0000020	*nil*
Mudon . .	335 c. c. .	5 weeks	1·34″	0·00259	0·00078	*nil*	0·0000050	*nil*

[Ammonia stated in terms of nitrogen.]

The rate of percolation obviously slowed down considerably during the five weeks which the experiment lasted, but assuming that no such slowing down occurred, the following amounts of added nitrogen would have been lost in six months :—

	Per cent.	
From Akyab soil	95	Approximately.
„ Mandalay soil	11	
„ Hmawbi „	6	
„ Mudon „	6	

It is seen that Mudon and Hmawbi lose about equal amounts of nitrogen, while Mandalay loses a little more and Akyab most of all. No appreciable amount of phosphate was lost in any case. It is obvious that had it been possible to continue observations for the whole period of six months instead of assuming that the rate achieved in 5 weeks would be continued, the nitrogen found in percolates would have diminished considerably and the losses of nitrogen by drainage would have been found to be much smaller. The very empirical nature of the experiment must also be remembered ; likewise the absence of a growing crop which would have competed for the nitrogen. It may be noted that loss of phosphate from highly unsaturated soils under heavy rainfall does occur [Robinson and Jones, 1927]. Basic slag has been found to be fugitive under such conditions.

D. Assuming that ammonia is chiefly exchanged in the ordinary way as a replaceable base, loss of ammonia would not be expected unless the finer particles of soil are carried over the tops of the bunds by heavy rain or floods.

In actual practice the depth of the cultivated layer of paddy soils is 5″-6″ at most. Winchester quart bottles containing samples of 1 kg. each of Mandalay, Mudon, Akyab and Hmawbi paddy soils were taken and distilled water added until on settling the depth of water over the soils was about 5″. The actual relative amounts of dry soil and water used were one of soil to two of water. This corresponds fairly well with a depth of 5″ of water over a cultivated paddy field. To each bottle was added Leunaphos = 0·1 grm. nitrogen, the bottles were shaken vigorously for about one minute and subsequently allowed to stand. The Leunaphos used in all experiments quoted had the following analysis :—

	Per cent.
Water soluble P_2O_5	17·49
Citrate „ „	0·85
„ insoluble P_2O_5	*nil.*
Total P_2O_5	18·34
Nitrogen	19·51

The experiment was done in duplicate. One series was sampled after 43 hours and the other after nine days, as much water as possible being siphoned off in each case, taking care not to disturb the upper layers of soil. At the time of sampling the turbidities of the supernatant liquids were as follows in both cases :—

Akyab > Mudon > Hmawbi > Mandalay.

The results of analysis are given in Table II.

TABLE II.

Fertilizing constituents in solution or suspension (grams per litre).

Time of standing	Soil	Ammonium salts (as N)	Albuminoid ammonia (as N)	Nitrate N	Nitrite N	P_2O_5
43 hours	Akyab	0·01711	0·00166	*nil*	*nil*	Traces.
43 hours	Mandalay	0·00392	0·00083	*nil*	*nil*	Slight traces
43 hours	Mudon	0·01330	0·00218	*nil*	*nil*	Very faint traces.
43 hours	Hmawbi	0·00550	0·00089	*nil*	*nil*	*Nil.*
9 days	Akyab	0·01873	0·00321	*nil*	*nil*	Traces.
9 days	Mandalay	0·00253	0·00380	0·00034	0·00008	Traces.
9 days	Mudon	0·01482	0·00502	*nil*	*nil*	*nil.*
9 days	Hmawbi	0·00428	0·00250	*nil*	*nil*	*nil.*

A depth of 5″ of water over one acre corresponds to 1,130,000 lbs. of water approximately. Table II may be re-written showing the number of pounds of fertilizing constituents in solution or suspension after 43 hours and 9 days, respectively. These data are shown in Table III.

TABLE III.

Lbs. per acre of fertilizing constituents in solution or suspension.

Time of standing	Soil	Ammonium salts (as N)	Albuminoid ammonia (as N)	Nitrate N	Nitrite N	P_2O_5
43 hours . .	Akyab . .	19·33	1·88	*nil*	*nil*	Traces
43 hours . .	Mandalay .	4·43	0·94	*nil*	*nil*	Traces
43 hours . .	Mudon . .	15·03	2·46	*nil*	*nil*	Traces
43 hours . .	Hmawbi . .	6·22	1·00	*nil*	*nil*	*nil*
9 days . .	Akyab . .	21·16	3·63	*nil*	*nil*	Traces
9 days . .	Mandalay .	2·86	0·43	0·38	0·09	Traces
9 days . .	Mudon . .	16·75	5·68	*nil*	*nil*	*nil*
9 days . .	Hmawbi . .	4·84	2·83	*nil*	*nil*	*nil*

If it is assumed that the cultivated layer of paddy soil weighs 1,000,000 lbs. per acre, a figure fairly near the actual, the amount of Leunaphos applied corresponds to 100 lbs. of nitrogen per acre. This is a rather heavy dressing, but smaller quantities caused difficulties in analysis because actually the amounts of the various soils in hand were not very great, and hence only one-tenth of the previously used quantities could be made use of in later experiments.

It was considered that the rough experiments described clearly showed that a large part of the nitrogen in ammonium phosphate manures, such as Leunaphos, may remain either in true solution or in suspension almost indefinitely under paddy field conditions, and is therefore very liable to be lost if the water rises over the bunds. Under comparatively dry conditions run-off water from plots under a comparatively low rainfall of 36″-37″ per annum has been found to contain negligible amounts of plant food in solution, calcium and sulphur only being of importance. On the other hand, the eroded soil contained as much as 98·8 lbs. N and 47·4 lbs. P, per acre [Duley, 1926]. Further, no fertilizer was applied to these plots.

AMMONIA AND PHOSPHATE RETAINED BY THE VARIOUS SOIL FRACTIONS.

Among the four paddy soils previously described, only the Mandalay soil is calcareous. In Burma only the sour soils are of real importance, the vast majority of the crop being raised on sour soils. Hence for much of the experimental work subsequently described, Mudon soil was the only one used. Mechanical analyses of all soils used are shown in Table IV below, certain chemical data also being shown.

TABLE IV.

Mechanical analyses of soils used.

(Clay=10·0 cms. in 8 hours at 20°C.)

	Akyab	Mandalay	Mudon
Coarse sand	43·07	7·24	4·44
Fine sand	37·78	31·04	40·98
Silt	10·92	15·00	29·89
Clay	8·83	41·32	25·23
Moisture lost at 100°C.	0·98	5·42	3·16
Carbonates	*nil*	1·04	*nil*
Solution loss	0·19	1·41	0·46
Difference	—1·77	—2·47	—4·16
Total	100·00	100·00	100·30
Organic carbon	0·775	0·256	1·338
Loss on ignition	4·314	9·594	9·038

Mechanical analysis of Hmawbi Soil.

(Clay=8·6 cms. in 24 hours at 15°C.)

Coarse sand	1·1
Fine sand	10·0
Silt	23·9
Fine silt	52·1
Clay	14·7
	101·8
$CaCO_3$	*nil*

Mudon soil, distilled water and nitrogen (as Leunaphos) were mixed in the proportions 1,000 grm., 2,000 c. c. and 0·1 grm., respectively, thoroughly shaken for several minutes, and then sedimented as in ordinary mechanical analysis but with

no alkali added. Aliquots were withdrawn to represent the clay, clay *plus* silt and average sample, although the latter gave considerable trouble since it is not easy to sample soil/water mixtures containing fair amounts of coarse fractions. The results of analysis for nitrogen and phosphate are shown in Table V.

TABLE V.

Distribution of ammonia (as N) and P_2O_5 in soil fractions (grams per litre).

	Ammonium salts (as N)	P_2O_5
Average sample.	0·0434	0·0457
Silt *plus* clay	0·0494	0·0472
Clay	0·0158	0·0088

The time/depth ratios used were 10·0 cms. in 8 hours at 20°C. for clay and correspondingly for silt.* It should be noted, however, that the soil aggregates were in no way broken up and the coarser fractions would have a coating of clay. Also the concentration of soil in water was many times greater than is customary in mechanical analysis by sedimentation. In spite of these limitations, it appears clear that the whole of the ammonia and phosphate which is absorbed or exchanged by the soil particles is removed by the fine particles of silt and clay (Atterberg Scale), but whereas about 30 per cent. of the ammonia in the given soil is withdrawn by the clay or is in true solution, a much smaller amount of phosphate is in true solution, or on the clay particles. Hence although losses of ammonia from paddy soils may be serious, losses of phosphate will be correspondingly smaller.

EFFECT OF VARIOUS TREATMENTS OF SOIL ON AMMONIA AND P_2O_5 RETAINED BY THE CLAY FRACTION.

Mudon soil is moderately sour paddy soil, pH=5·95. It was therefore decided to lime to neutrality with various reagents and to add organic matter in various forms to see if the fertilizing constituents carried by the clay or in solution could be reduced. For this purpose the soil was neutralized with $CaCO_3$, $Ca(OH)_2$ and a mixture of $Ca(HCO_3)_2$ and $CaCO_3$, since in the proportions of soil and water used, $Ca(HCO_3)_2$ solution could not bring the soil to neutrality. The Lime Requirement was determined by Hardy and Lewis's method [1929], and was found to be 0·2144 grs. CaO per 100 grm. soil. In addition, one lot of 1,000 grm. soil received a dressing of $2\frac{1}{2}$ grm. cattle manure, which was equivalent under the conditions to one ton per acre approximately, and a further lot received $2\frac{1}{2}$ grm. paddy straw. To each bottle containing the soil and water mixture was added 0·1 grm. N as Leunaphos, and the bottles were shaken vigorously for a few minutes. The clay fractions of each were sampled at once, after one week, one month, and after nine weeks, using the depth ratio for clay 10 cms. in 8 hours at 20°C. In the samples withdrawn the

* Revised Official British Method for Mechanical analysis [*J. Agri. Sci.* **18** (1928), pp. 734-739.]

ammonium salts and albuminoid ammonia were determined by Nesslerization, and the P_2O_5 was determined by the ammonium phospho-molybdate method. Results are given in the Table VI.

TABLE VI.

Fertilizing constituents in clay fractions of soil with varying treatments (Leunaphos = 0·1 grm. N added).

(Soil = 1000 grm.; water = 2000 c.c.; NH_4 (as N) and P_2O_5 in grm. per litre.)

——	Untreated soil	2½ grm. cattle manure	2½ grm. paddy straw	Limed with $CaCO_3$	Limed with $Ca(OH)_2$	Limed with $Ca(HCO_3)_2$ *plus* $CaCO_3$
First day.						
NH_4 salts	0·01580	0·01976	0·01872	0·01672	0·01692	0·01701
Albuminoid ammonia	0·00486	0·00741	0·00754	0·00758	0·01590	0·00103
P_2O_5	0·0038	0·0164	0·0125	0·0150	0·0175	*nil.*
After one week, shaking night and morning.						
Ammonium salts	0·01564	0·01528	0·01548	0·01375	0·01293	0·01569
Albuminoid ammonia	0·00622	0·00741	0·01688	0·00272	0·00268	0·00185
P_2O_5	0·0113	0·0138	0·0250	0·0075	*nil.*	*nil.*
After one month, shaking night and morning.						
Ammonium salts	0·01688	0·01976	0.01260	0·01952	0·01635	0·01688
Albuminoid ammonia	0·00663	0·01952	0·00226	0·00144	0·00074	0·00050
P_2O_5	0·0163	0·0288	traces.	*nil.*	*nil.*	traces.
After nine weeks, shaking night and morning.						
Ammonium salts	0·02075	0·02701	0·01804	0·02092	0·02186	0·02541
Albuminoid ammonia	0·01872	0·02872	0·00231	0·00107	0·00124	0·00124
P_2O_5	0·0213	0·0451	0·0075	traces.	traces.	*nil.*

From these results it is seen that the various treatments have the following effects after nine weeks :—

1. No treatment. NH_4 salts, alb. NH_3 and P_2O_5 all increase considerably.

2. Cattle manure. As No. 1 but to a greater extent.
3. Paddy straw. NH_4 salts remain approximately constant, while alb. NH_3 and P_2O_5 diminish.
4. Liming with $CaCO_3$, $Ca(HCO_3)_2$ or $Ca(OH)_2$.

The final effect of liming to neutrality is that NH_4 salts remain substantially as in the untreated sample, whereas albuminoid ammonia and P_2O_5 are diminished, the latter becoming negligible. Since loss of P_2O_5 is in general not feared, none of the above treatments is of much use in reducing loss of fertilizing constituents in what may be regarded as the clay fraction.

The Ultra-clay Fraction.

It now became of importance to discover whether the ammonia and P_2O_5 was actually on the clay particles or in solution. For this purpose it was first decided to allow the mixture of soil, water and Leunaphos to sediment so that fractions corresponding to one-tenth the size of clay particles could be obtained. At the average temperature of the laboratory, this corresponded to sampling at a depth of 5·6 cms. after 14 days.

At this time turbidities were as follows :—

Straw>	Untreated>	Lime treatment>	Cattle manure
(Reddish yellow.)	(Opalescent.)	(All slightly yellow and faintly opalescent.)	(Water clear and no colour.)

Results are given in Table VII.

Table VII.

Fertilizing constituents in ultra-clay fraction of soil. (Leunaphos = 0·1 grm. N added.)

[Soil = 1000 grm. ; water = 2000 c.c. ; NH_4 (as N) in grms. per litre.]

—	Untreated soil	2½ grm. cattle manure	2½ grm. straw	Limed with $CaCO_3$	Limed with $Ca(OH)_2$	Limed with $Ca(HCO_3)_2$ *plus* $CaCO_3$
NH_4 salts	0·01532	0·01581	0·01696	0·02302	0·00614	0·01071
Alb. NH_4	0·00041	0·00066	0·00115	0·00033	0·00021	0·00144
P_2O_5	*nil.*	*nil.*	*nil.*	*nil.*	*nil.*	*nil.*

From these results it appears that liming with $Ca(OH)_2$ or a mixture of $Ca(HCO_3)_2$ and $CaCO_3$ tends to reduce the ammonia on the ultra-clay particles, but on the other hand, treatment with $CaCO_3$ alone had no such effect. The absence of P_2O_5 in all cases is noteworthy. Soluble P_2O_5 is completely withdrawn from solution before the lapse of nine weeks whether the soil is treated with cattle manure, straw, or limed, or remains untreated.

It was thereupon decided to centrifuge the soil/water mixtures until they were quite clear, in order to discover whether the ammonia was actually carried by fine clay particles, or was in solution. The mixtures were centrifuged for four to five hours at gravity × 1500 with the results given in Table VIII.

TABLE VIII.

Ammonia in solution after 9 weeks' contact with soil. Leunaphos=0·1 grm. N added.

[Soil=1000 grms.; water=2000 c.c.; NH_4 (as N) in grams per litre.]

	Untreated soil	2½ grm. cattle manure	2½ grm. paddy straw	Limed with $CaCO_3$	Limed with $Ca(OH)_2$	Limed with $Ca(HCO_3)_2$ *plus* $CaCO_3$
NH_4 salts	0·01610	0·01474	0·01659	0·01808	0·00354	0·00947
Alb. NH_4	*Nil.*	*Nil.*	0·00144	0·00021	0 00016	0·00144
pH	5·6	6·1	6·8	7·2	7·3	7·2

It is therefore quite clear that even with a dosage of approximately 100 lbs. N per acre, applied to wet paddy land in absence of a crop, considerable amounts of nitrogen may remain in solution in the water even after an interval of nine weeks. Whether liming would or would not reduce this remained uncertain. From the pH of the water after centrifuging it appeared possible that the smaller amounts of ammonia occasioned by liming with $Ca(OH)_2$ and $Ca(HCO_3)_2$ as compared with $CaCO_3$ might be due to slightly heavier doses of CaO in these cases. To discover whether this was so or not, it was decided to lime the Mudon soil with increasing quantities of $CaCO_3$. The lime requirement of the soil is 0·2144 grm. CaO or 0·383 grm. $CaCO_3$ per 100 grm. soil. To a series of 100 grm. soils in shaking bottles was added *nil*,

0·2 grm., 0·4 grm., 0·6 grm., 0·8 grm. and 1.0 grm. $CaCO_3$. To each was then added 200 c.c. distilled water, and the flasks were closed, and shaken for 2 days in an end-over-end shaking machine. Subsequently Leunaphos = 0·01 grm. nitrogen was added to each, and the flasks again shaken for 2 hours, after which the contents of the flasks were centrifuged for 4 hours and the clear extract analysed for ammonium salts, and albuminoid NH_4.

Results are shown in Table IX.

TABLE IX.

The effect of liming beyond neutrality on ammonia in solution. Leunaphos=0·1 grm. N added.

[Soil=1,000 grms. ; water=2,000 c.cs. NH_4 (as N) in grms. per litre.]

——	No lime	0·2 grm. $CaCO_3$	0·4 grm. $CaCO_3$	0·6 grm. $CaCO_3$	0·8 grm. $CaCO_3$	1·0 grm. $CaCO_3$
NH_4 salt	0·01692	0·01480	0·01614	Spoiled.	0·01882	0·01960
Alb. NH_4	*Nil.*	0·00049	0·00124	Spoiled.	0·00062	*Nil.*

The results in Table IX indicate that heavy liming tends on the whole to increase the amount of NH_4 salts in solution in the soil-water. The reason for the low results obtained with soils which had stood in contact with water for prolonged periods is not understood, but the conditions did not preclude bacteriological activity. Certainly $CaCO_3$ has no beneficial effect immediately, and whether it would do so after a longer time can perhaps be best settled by studying a calcareous soil in its relationship with ammonia solutions.

DISTRIBUTION OF AMMONIA AND P_2O_5 IN SOIL AND WATER WITH VARIOUS SOILS.

It was first of all necessary to determine a suitable time for reaction between soil, water and fertilizer. Accordingly 100 grms. soil, 200 c.c. water and 0·01 grm. N as Leunaphos were shaken with Mandalay, Mudon and Akyab soils for 15 minutes, 2 hours and 20 hours, respectively. In this and all subsequent experiments the temperature was kept as nearly as possible at 30°C., but a thermostat was not available. Actually variation was about ± 1°C. After this time the solutions were centrifuged till clear and analysed for ammonia and P_2O_5. The results obtained are shown in Table X.

TABLE X.

Varying the period of shaking.

(Soil=1.000 grms.; water=2,000 c.c.; Leunaphos=0·51 grms.; N and P_2O_5 as grms. per 2000 c.c.

—	—	Mandalay	Mudon	Akyab
15 minutes' shaking	Ammonium salts .	0·00371	0·03260	0·05440
	Albuminoid ammonia	0·00371	0·00494	0·01150
	P_2O_5 . . .	0·0040	0·0030	0·0120
2 hours' shaking .	Ammonium salts .	0·00695	0·02545	0·05600
	Albuminoid ammonia	0·00050	0·00247	0·00190
	P_2O_5 . . .	0·0021	<0·0005	0·0060
20 hours' shaking .	Ammonium salts .	0·00576	0·03100	0·03665
	Albuminoid ammonia	0·00082	0·00206	0·00716
	P_2O_5 . . .	0·0005	<0·0005	Faint traces only.

It appears clear that the reaction between soil and ammonia is generally more quickly completed than the reaction between soil and phosphate. Two hours appeared to be a suitable time of reaction, and this was adopted in all further experiments. The fact that phosphate absorption appears to be incomplete in two hours should be noted.

The results obtained with Mandalay, Akyab, Mudon and Hmawbi soils under such conditions are given in Tables IX to XIV. The smaller quantities of ammonia in solution were determined by Nesslerization. In the case of the phosphate estimation this was done by the phospho-molybdate method, but quantities which could not be titrated were estimated by inspection of the amount of yellow phosphate. It was not considered worthwhile to adopt a more accurate method for estimating smaller quantities of phosphate as it was obvious that losses of phosphate were of a much smaller order of magnitude than losses of ammonia.

Freundlich's equation $\frac{y}{m} = k\,C\,\frac{1}{p}$, in which y is the amount of ammonia or P_2O_5 absorbed by m grms. of soil, C the equilibrium concentration of the solution after two hours' shaking; k and p being constants, was applied to the results for both

ammonia and phosphate absorptions. Graphs I and II show these results for ammonia and P_2O_5 respectively, log C being plotted against log y.

TABLE XI.

Varying the dosage of Leunaphos when amounts of soil and water are constant.—Mandalay soil.

(Soil=1,000 grms.; water=2,000 c.cs.; N and P_2O_5 as grams per 2,000 c.cs.)

Leunaphos applied .	*Nil.*	0·0512	0·1024	0·2560	0·5125	5·125	51·25*	512·5†
=Nitrogen . . .	*Nil.*	0·0100	0·0200	0·0500	0·1000	1·0000	10·0000	100·0000
$=P_2O_5$ . . .	*Nil.*	0·0094	0·0188	0·0470	0·0940	0·9400	9·4000	94·0000
NH_4 Salts (as N) in solution (C).	0·00050	0·00082	0·00102	0·00272	0·00695	0·22400	5·18000	78·4000
Albuminoid NH_3 (as N).	0·00090	0·00056	0·00054	0·00033	0·00050	0·00092	0·00514	0·0461
NH_4 (as N) absorbed (y)	..	0·00918	0·01898	0·04728	0·09305	0·7760	4·8200	21·6000
P_2O_5 in solution (C) .	..	..	..	..	0·0021	0·0621	1·9030	62·0900
P_2O_5 absorbed (y) .	..	..	..	..	0·0919	0·8779	7·4970	31·9100

* Faintly coloured. † Strong yellow brown colour.

TABLE XII.

Varying the dosage of Leunaphos when amounts of soil and water are constant—Akyab soil.

(Soil=1,000 grms.; water=2,000 c. cs.; N and P_2O_5 as grams per 2,000 c. cs.)

Leunaphos applied .	*Nil*	0·0512	0·1024	0·2560	0·5125*	5·125	51·25	512·5
=Nitrogen . . .	*Nil*	0·0100	0·0200	0·0500	0·1000	1·0000	10·0000	100·0000
$=P_2O_5$ . . .	*Nil*	0·0094	0·0188	0·0470	0·0940	0·9400	9·4000	94·0000
NH_4 Salts (as N) in solution (C).	0·00200	0 00596	0·00949	0·02540	0·05600	0·74620	8·5400	84·0000
Albuminoid NH_4 (as N)	0·00227	0·00175	0·00263	0·00288	0·00190	0·00425	0·01936	0·08565
NH_4 (as N) absorbed (y)	...	0·00404	0·01051	0·0246	0·0440	0·2 538	1·1600	16·0000
P_2O_5 in solution (C) .	*Nil*	*Nil*	*Nil*	0·0008	0·0060	0·4380	7·5110	72·6100
P_2O_5 absorbed (y) .	...	...	...	0·0462	0·0880	0·5020	1·8890	21·3900

* Faintly coloured yellow. Extracts with greater dosages stronger yellow colour.

TABLE XIII.

Varying the dosage of Leunaphos when amounts of soil and water are constant—Mudon soil.

(Soil=1,000 grms. ; water= 2,000 c. cs. N and P_2O_5 as grams per 2,000 c. cs.)

Leunaphos supplied .	*Nil*	0·0512	0·1024	0·2560	0·5125	5·125	51·25*	512·5*
=Nitrogen . . .	*Nil*	0·0100	0·0200	0·0500	0·1000	1·0000	10·0000	100·0000
$=P_2O_5$ . . .	*Nil*	0·0094	0·0188	0·0470	0·0940	0·9400	9·4000	94·0000
NH_4 salts (as N) in solution (C).	0·00068	0·00122	0·00356	0·01211	0·02545	0·5872	8·1090	75·0710
Albuminoid NH_4 (as N)	0·00264	0·00267	0·00247	0·00920	0·00247	0·00234	0·02293	0·03519
NH_4 (as N) absorbed (*y*)	...	0·00878	0·01641	0·03789	0·07455	0.4128	1·8910	24·9290
P_2O_5 in solution (C) .	*Nil*	*Nil*	*Nil*	...	0·0005	0·0581	3·1040	59·0800
P_2O_5 absorbed (*y*) .	...	...	...	...	0·0935	0·8819	6·2960	34·9200

* Strongly coloured yellow-brown.

TABLE XIV.

Varying the dosage of Leunaphos when amounts of soil and water are constant—Hmawbi soil.

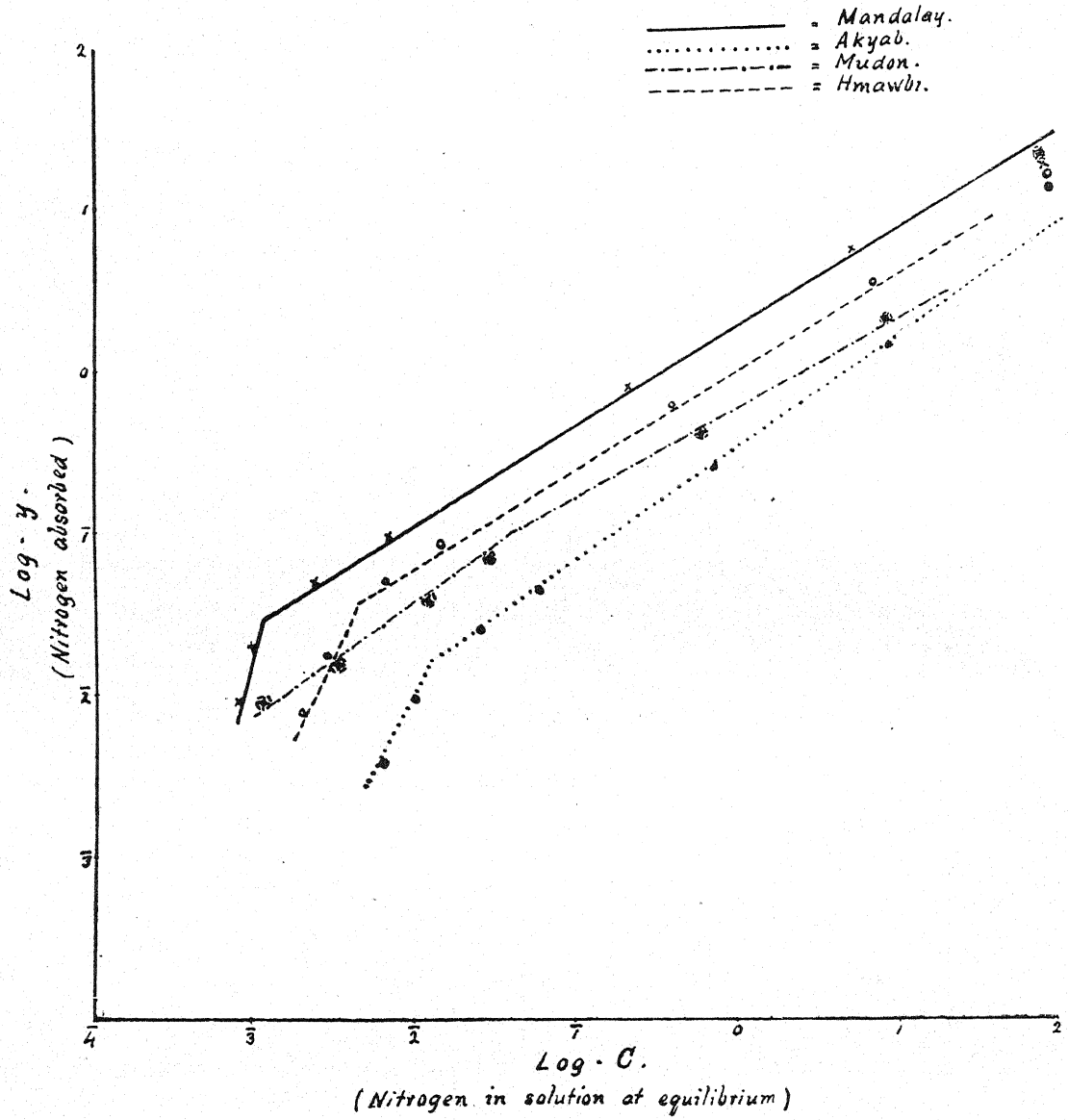
(Soil=1,000 grms. ; water=2,000 c. c. N and P_2O_5 as grams per 2,000 c. c.)

Leunaphos applied .	*Nil*	0·0512	0·1024	0·2560	0·5125	5·125	51·25*	512·5*
=Nitrogen . . .	*Nil*	0·0100	0·0200	0·0500	0·1000	1·0000	10.0000	100·0000
$=P_2O_5$ . . .	*Nil*	0·0094	0·0188	0·0470	0·0940	0·9400	9·4000	94·0000
NH_4 salts (as N) in solution (C).	0·00161	0·002174	0·00300	0·00733	0·01532	0·40600	7·1400	79·8000
Albuminoid NH_4 (as N)	0·00161	0·00099	0·00148	0·00288	0·00132	0·00221	0·0075	0·0651
NH_4 (as N) absorbed (*y*)	...	0·007826	0·01700	0·04267	0·08468	0·5940	2·8600	20·2000
P_2O_5 in solution (C) .	*Nil*	*Nil*	...	...	0·0005	0·0676	3·3800	69·1000
P_2O_5 absorbed (*y*) .	...	...	...	...	0·0935	0·8724	6·0200	24·900

*Strongly coloured yellow-brown.

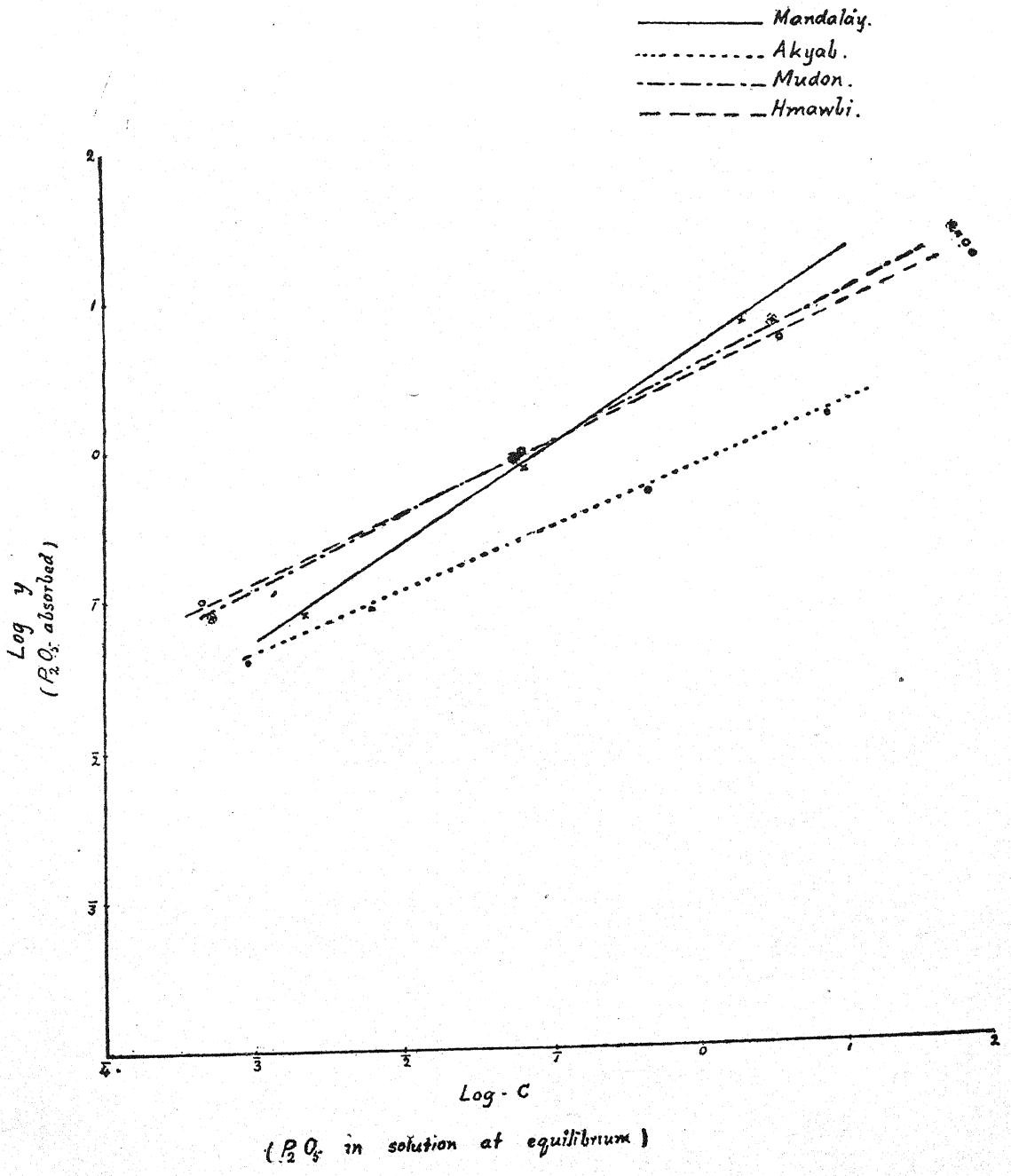
Graph 1

Ammonia absorption



Graph II

(P_2O_5 absorption)



The fact that the absorption of ammonia or P_2O_5 may be plotted on a curve which obeys Freundlich's equation does not necessarily mean that the reaction is an absorption [Fisher, 1921]. This equation applies to reactions which are not absorptions and breaks down in the case of absorption of potash by soil as in the results obtained by Peters [1860]. These results of Peters for potash absorption bear a close resemblance to the absorption of ammonia shown in Graph I. In the results for all the four soils examined, a break in the curves was obtained, which indicates that if absorption of ammonia does occur, it is also probably accompanied by base exchange.

The base exchange hypothesis does not explain absorption of phosphates and other acid radicals. Over comparatively small ranges of concentration it is, however, quite easy to fit results to Freundlich's equation. It was assumed by Russell and Prescott [1916] and by Harrison and Das [1921] that because the results for P_2O_5 absorption by soils could be made to fit such an equation that this indicated an absorption. Fisher [1921] has shown that this is not necessarily the case. The results obtained for absorption of P_2O_5, apart from those in very high concentrations of phosphate which are obviously affected by questions of solubility, have not been extended further than was necessary to show that P_2O_5 is in solution to only a negligible extent with ordinary applications of fertilizer. Thus from Graph II, if the various graphs are solved at log C=3·0 and log y=at 1·0, the following values are obtained :—

Mandalay soil :—	An application of	(*a*)	57·2 lbs.	P_2O_5 gives	1	lb. P_2O_5 in	solution.
	,, ,, ,,	(*b*)	102·5 ,,	,, ,,	2·5	,, ,,	,,
Akyab soil :—	,, ,, ,,	(*a*)	51·12 lbs.	,, ,,	1	,, ,,	,,
	,, ,, ,,	(*b*)	106·3 ,,	,, ,,	6·31	,, ,,	,,
Mudon soil :—	,, ,, ,,	(*a*)	129·8 ,,	,, ,,	1	,, ,,	,,
	,, ,, ,,	(*b*)	100·6 ,,	,, ,,	0·63	,, ,,	,,
Hmawbi soil :—	,, ,, ,,	(*a*)	142·3 ,,	,, ,,	1	,, ,,	,,
	,, ,, ,,	(*b*)	100·45 ,,	,, ,,	0·45	,, ,,	,,

The amounts of P_2O_5 in solution at equilibrium are in no case as high as 2·5 per cent. for a normal application of soluble phosphate, *i.e.*, about 40 lbs. P_2O_5 per acre. The fact that absorption continues for longer than two hours should also be remembered. It is taken as conclusive that under any ordinary conditions whereby erosion is not encountered, serious loss of phosphate from paddy soils is not to be feared.

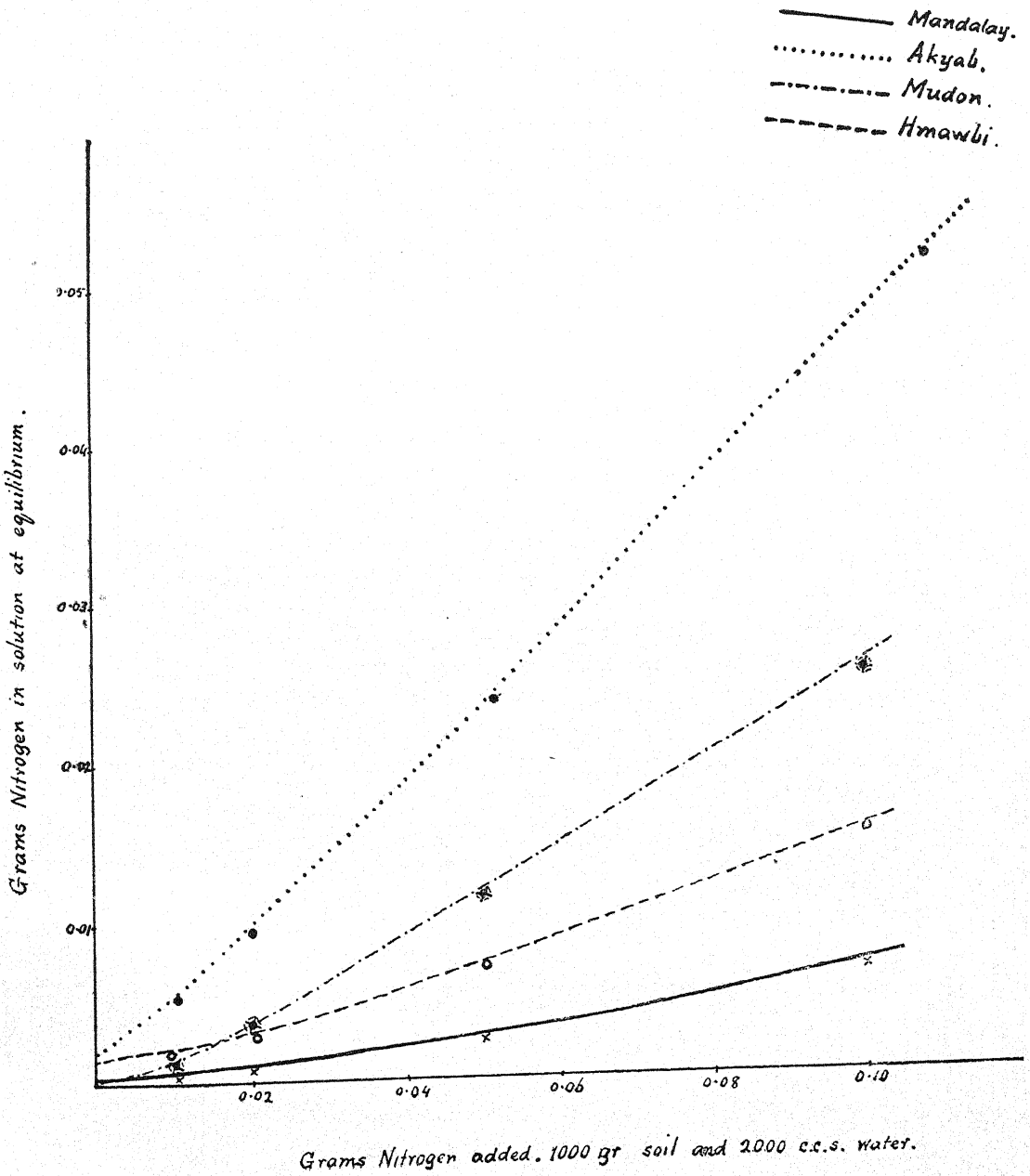
The curves for absorption of ammonia exhibit a distinct break in the region of amounts usually applied, *i.e.*, about 40 lbs. per acre (as N). It was therefore considered inadvisable to determine the amounts in solution at equilibrium from Graph I, but to draw a fresh graph plotting the amounts of ammonia added against that in solution. This has been done in Graph III. Graph III shows that at applications of 40 lbs. per acre of nitrogen as Leunaphos under the conditions laid down, the following amounts of nitrogen are in solution :—

Mandalay . .	2 lbs. N or 5.	Per cent.
Hmawbi . .	6 ,, ,, ,, 15.	
Mudon . .	9 ,, ,, ,, 22·5.	
Akyab . . .	20·5 ,, ,, ,, 51·25.	

These figures indicate the vast difference in possibilities of losses of ammonia and phosphate. Whereas phosphate losses may be regarded as negligible, the possibilities of loss of ammonia are very great indeed.

Graph III

Ammonia absorption.



THE EFFECT OF THE REPLACEABLE BASES IN SOILS ON FERTILIZING CONSTITUENTS ABSORBED.

The failure of excess of lime to have any notable effect on the amount of ammonia in solution at equilibrium with Mudon soil left open the possibility that replaceable bases other than calcium might have a considerable effect on the equilibrium. In other words, ammonia might be more readily exchanged for sodium, potassium, hydrogen or magnesium than for calcium. Actually the replaceable bases present in the four soils tested as determined by electrodialysis are as follows:—

Soil	In milli-equivalents per 100 grm. soil			
	Total Bases	Calcium	Magnesium	Monovalent (By difference)
Mandalay . . .	38·76*	21·70*	16.53*	0·53
Akyab	3·60	0·25	3·30	0·05
Mudon	5·32	1·87	1·30	2·15
Hmawbi. . . .	5·90	0·30	2·16	2·44

As insufficient Hmawbi soil was left, Mandalay, Akyab and Mudon soils only were treated. Hydrogenated soils were produced by exhaustive treatment with N/20 HCl until no more calcium was extracted. The soils were then washed free from chloride with distilled water. Calcium, magnesium, sodium and potassium soils werep roduced by repeated treatment with normal chloride solutions after which the soils were washed free from chloride with distilled water. The heavier soils gave such trouble in producing sodium clay that the production of a Mandalay sodium clay was abandoned. In this case it was found that there remained in solution, or very finely divided condition, a mixture of iron and aluminium silicates in such large amount that the loss occasioned to the soil was very considerable. The silicates referred to could be removed by traces of various electrolytes, and on analysis one such precipitate was found to have the following composition :—

	Per cent.
Silica ($Si O_2$) . . .	63·30.
Alumina ($Al_2 O_3$) . .	22·39.
Iron Oxide ($Fe_2 O_3$) .	11·46.
Total .	97·15.

* Includes carbonates.

The remaining treated soils prepared from 100 grms soil referred to were dried at 50°C., added to 200 c.c. distilled water and 0·05125 grm. Leunaphos added, after which the mixtures were shaken for two hours, centrifugalised and the soil solutions analysed for ammonia and P_2O_5. The results are given in Table XV.

TABLE XV.

Effect of replaceable bases on absorption of ammonia and P_2O_5.

[Ammonia (as N) and P_2O_5 in grams per 2000 c.c.]

	Leunaphos applied		Ammonia in solution (as N)	Albuminoid ammonia (as N)	P_2O_5
	=Nitrogen	=P_2O_5			
H· soils — Mandalay	0·10000	0·0940	0·00996	*Nil.*	*Nil.*
H· soils — Akyab	,,	,,	0·05493	0·00280	0·0100
H· soils — Mudon	,,	,,	0·03360	0·00478	0·0010
Ca· soil—Mudon	,,	,,	0·03072	0·00412	traces only.
Mg. soil—Mudon	,,	,,	0·03279	0·00296	*Nil.*
K· soil—Mudon	,,	,,	0·01293	0·00758	0·0050
Na· soils — Mudon	,,	,,	0·00395	0·00576	0·0070
Na· soils — Akyab	,,	,,	0·00733	0·00618	0·0301

The effect of changing the replaceable bases in the various soils may be summarized as follows :—

Hydrogen.—The ammonia present at equilibrium is slightly increased in all soils, the albuminoid ammonia being insignificantly affected, while the P_2O_5 in solution is diminished in amount in two cases and increased in the other (Akyab). The Akyab soil contained 10·6 per cent. of the P_2O_5 in solution at equilibrium. Absorption of phosphate would not be expected under these conditions, as Van Bemmelen showed in 1878 that soils thoroughly free from replaceable bases did not absorb phosphate. Some replaceable base was introduced with the fertilizer itself, however.

Calcium and magnesium.—These were only tried with the Mudon soil, and have little effect on the ammonia content of the soil solution, whereas both diminished the P_2O_5 content of the soil solution.

Potassium.—This was only tried with the Mudon soil, and was found greatly to diminish the ammonia, slightly to increase the albuminoid ammonia, and considerably to increase the phosphate content of the soil solution. The P_2O_5 in solution amounted to 5·3 per cent.

Sodium.—This was tried with Mudon and Akyab soils, and greatly diminished the ammonia, had little effect on albuminoid ammonia, but greatly increased the P_2O_5 in solution at equilibrium. In the case of Akyab soil, about 32 per cent. of the P_2O_5 applied was found in solution.

It therefore follows that the ammonia applied to paddy soils is exchanged most readily for sodium followed by potassium, but calcium, magnesium and hydrogen are roughly equivalent in ease of exchange and far inferior to sodium and potassium. On the other hand, the presence of large amounts of replaceable sodium and potassium, particularly the former, results in rather a large proportion of P_2O_5 remaining in solution at equilibrium.

The fact that permutites can take up a large proportion of their weight of P_2O_5 as dihydrogen phosphate but less as monohydrogen phosphate, chiefly as aluminium phosphate which is insoluble in water and soluble in citric acid [Berl and Schmittner, 1929], offers an interesting study of alternative methods of application of phosphate, more especially as the necessary ammonia may also be applied as permutite also. Van Nostitz [1925] has shown that plants made better growth in sand cultures when Ca, Mg and K were supplied as permutite complexes than as soluble salts. As yet the author has made no actual tests with such permutites on the growth of paddy, but hopes to do so in the future.

Remedial Measures.

It is frequently stated that ammonia, as its salts, is completely absorbed by soil [Russell, 1919]. This statement though true for conditions of ordinary dry-farming does not hold for the manuring of paddy. Ammonia as Leunaphos and other similar manures is absorbed or exchanged by the soil to an extent depending upon the relative amounts of soil, water and ammonia applied, and it has been shown that the specific nature of the soil as regards its replaceable bases is of considerable importance.

In its first manifestations, the problem arose in paddy lands subject to very heavy rainfall with the result that it is most likely that the experimental plots, both treated and control plots, were covered by a uniform sheet of water on one or more occasions. It would therefore be inevitable for the control plots to benefit from ammonia applied to manured plots, thus tending to level up yields. The problem is therefore stwofold, first a regards experimental work, secondly for ordinary field-

work. Certain general considerations, however, apply to both. These are as follows :—

1. Since the more water there is over the soil at any time, the higher the total ammonia in solution, it is sound practice to drain off as much water as possible prior to applying the fertilizer.
2. Bunds should be as sound as possible and as high as is necessary to prevent water rising over the top. In many localities practical difficulties are, of course, very great.

In experimental work, each plot should be provided with a separate drainage channel so that in case of heavy rains, the use of such channels may serve to prevent the water submerging the individual plots.

In the case of a cultivator applying the fertilizer to his fields, the chief concern is to prevent loss of ammonia from his land. This may be achieved in several ways in addition to the points previously enumerated, *e.g.*,—

1. The fertilizer may be applied in several small doses in the earlier stages of growth prior to flowering.
2. An unmanured margin may be left round the holding in such a way that the drainage water liable to contain nitrogen may flow over his own unmanured fields, *i.e.*, the higher portions only may be manured.
3. The lighter soils may be manured with only small applications of fertilizer.
4. Under certain conditions, claying light land may be feasible.

Summary and Conclusions.

1. In manuring paddy lands with the usual ammonium phosphate fertilizers, it has been shown :—
   (*a*) That the clay particles may carry a large part of the ammonia applied but very much less P_2O_5,
   (*b*) A considerable part of the ammonia applied may be in true solution, particularly on light land.

2. Manuring in the ordinary way with ordinary amounts of organic manures has little effect towards reducing possible losses of ammonia and phosphate.

3. Ammonia is exchanged primarily for replaceable sodium, then potassium, but the remaining replaceable bases are of less value as regards ability to replace ammonia.

4. Concurrently with the increased ability to replace ammonia, soils containing much replaceable sodium and potassium retain more P_2O_5 in the soluble state in the soil solution.

5. Means are suggested to minimize possible losses.

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MILLING AND BAKING TESTS WITH SOME INDIAN WHEATS GROWN AT PUSA AND AT MIRPURKHAS (SIND).

BY

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Quality in wheat is a relative term depending on the particular interests which are under consideration. To the grower high yielding power is perhaps the best and most important quality, while to the miller and baker those chemical and physical properties which determine the fitness of a wheat for a particular purpose hold first place. Of all the uses of wheat the most important is that of bread making, and the purpose of the present article is to describe the quality of certain Indian wheats with reference to their capabilities for making bread according to the standards which prevail in the United Kingdom. The term quality is therefore used in the present article as describing the suitability of a flour for making yeast-risen bread.

The experiments which form the subject of this article were undertaken with the object of investigating the quality of six Pusa wheats grown at Pusa and also under irrigation conditions in Sind; at the same time three Sind wheats and a sample of Choice White Karachi were included in the tests for comparison with the Pusa wheats. The results of the tests are published in full as an appendix to this article. Milling and baking tests with the earlier Pusa wheats were carried out from 1908 to 1914, and the results of these tests are published elsewhere [Howard and Howard, 1908, 1910, 1911, 1928; Howard, Leake and Howard, 1910, 1913, 1914]. The earlier Pusa wheats Nos. 4 and 12 are described as showing that "wheats of the highest class can be grown in India" [Howard, Leake and Howard 1914], and Pusa 52 is stated to yield a first class bread flour and to resemble in this respect Pusa 4 [Howard and Howard, 1928]. These three wheats were all included in the present experiments together with three new wheats Nos. 80-5, 111 and 114 which had not previously been tested. Among the new wheats No. 80-5 is a hybrid from a cross between Pusa 4 and Pusa 6; it has proved a heavy yielder in Bihar and in the Punjab, but has not so far been distributed on a large scale. Pusa 111 was discovered as a mutation in Pusa 4, and in morphological characters differs from the latter wheat only in possessing smooth glumes. This is a desirable character as the felted glumes of Pusa 4 hold moisture in damp weather and tend to increase the incidence of rust in the

head. It is similar to grain and yielding power to Pusa 4. Pusa 114 is a bearded wheat selected from a cross with Australian Federation. It is a wheat of good standing power, but has rather too long a growing period to give its best results in the Bihar climate.

The bushel weights of the six Pusa wheats grown at Pusa during 1925-30 are shown in the following Table :—

Wheat	Weight per bushel in lb.				
	1925-26	1926-27	1927-28	1928-29	1929-30
Pusa 4	64·9	63·0	63·25	63·9	65·07
Pusa 12	61·5	65·0	56·3*	63·3	62·0
Pusa 52	65·5	63·0	62·17	64·0	65·4 63·5*
Pusa 80-5	65·0	56·5*	55·9*	65·3	63·1
Pusa 111	..	..	..	..	66·0
Pusa 114	..	..	..	..	60·0*

All these wheats were grown in the Botanical Section at Pusa and at Mirpurkhas (Sind) in the season 1929-30, and samples were shipped from Pusa and Sind to London about May, 1930. With the samples of Pusa wheats from Sind there were included samples of three Sind wheats—C. P. H. 47, A. T. 38 and G. S. 25—bred by the Botanist in Sind and a trade sample of Choice White Karachi. Milling and baking tests on all these wheats were carried out by the Research Association of British Flour Millers (see Appendix).

For the proper understanding of these tests it is necessary to appreciate the factors which determine good baking quality in a flour. These factors are uniformity, colour, gas production, maltose content and diastatic activity, gluten or protein content and gluten quality.

Uniformity in quality while of the first importance to the miller is not an intrinsic property of any flour. It depends rather upon the growers in a particular area limiting cultivation to one particular type of wheat so that the miller can rely upon the produce of a particular area always exhibiting the same properties. The remaining qualities are, however, intrinsic qualities and in any flour will vary with the particular kinds of wheat from which the flour is made.

Colour is an important factor in a flour which, for the market in the United Kingdom, should be as nearly white as possible. The yellow tinge which exists in

* Crop attacked by rust.

flours is due partly to the presence of gluten, and sometimes to the presence of a small quantity of a yellow pigment, carotin. The Pusa wheats Nos. 4, 52, 80-5 and 111 grown at Pusa in these experiments produced " a deep creamy flour of the Manitoba type," while the same wheats grown in Sind " had a poorer rather greyer colour."* The wheat No. 114 grown at Pusa gave a flour distinctly whiter than that of No. 4, 52 or 80-5, and the flour from Pusa 12 is described as outstanding—of an excellent white colour. The same wheat, Pusa 12, grown in Sind gave the whitest flour of all the Sind samples, the next in order of merit being Pusa 114. Low grade and damaged wheats invariably give a dirty grey flour, and such wheats can only be used for blending to an extent which does not allow their inferior colour to have a marked effect on the flour. Various bleaching processes are used in the trade in improving the quality of flour.

Gas production in a flour is a measure of the power of the flour to produce sufficient carbon dioxide to ensure the adequate inflation of the dough. In popular language the dough must rise to the required degree. If gas production is insufficient, the loaf will be of small volume, inferior, stodgy and of close grain with an unattractive appearance. None of the 16 samples tested in these experiments were good gassers. Among the Pusa wheats Pusa 4 and Pusa 111 (Sind crop) were the best and Pusa 114 the worst in this respect. Unsatisfactory gas production is a common feature of Indian wheats and sometimes occurs in high grade Manitoba wheats. It is not a serious defect from the commercial standpoint as these wheats are used only in blends and their deficiency may be made good by mixing with wheats of high gassing capacity.

Some flours have a high natural content of maltose and high diastatic activity, and on this account maltose and dextrin accumulate during fermentation giving rise to a sticky dough. There is no cure for this trouble, which frequently occurs with frosted or immature grain ; it can be dealt with only by blending. The maltose figure in sound flour should not exceed 2·5 per cent. ; from the results of the analyses in the present tests the 16 samples all appear to be satisfactory in this respect.

The gluten or protein content of a flour is a most important quality ; if gluten content is below a certain minimum, good bread cannot be made. The straight flours from Manitoba wheats generally contain from 10 to 12 per cent. protein, Australian 8-13 per cent., Indian 7-9 per cent. English wheats generally have about the same value as the Indian. In this respect the Pusa wheats, whether grown at Pusa or in Sind, compare favourably with other wheats. The protein content of the flours from Pusa wheats ranges from 9·2 to 12·2 ; Pusa 111 has a content of 11·97 per cent. in Pusa, and 10·89 per cent. in Sind. The Sind wheats, samples 13-16,

* Appendix, page 403.

are appreciably lower in protein content than the Pusa wheats, and are about the normal protein content of commercial Indian wheats.

Gluten quality is the most difficult and least understood of the factors which go to make a good flour. Gluten consists chiefly of a mixture of two proteins, gliadin and glutenin. In a dough the gluten forms a complex mixture with water, in which starch and yeast are imbedded, and the physical properties of the dough depend upon the nature and amount of the gluten. The physical characters which are essential for a good dough are high water absorption, elasticity, ductility, toughness and stability. If these characters are present in a flour, the dough will retain the gas produced during fermentation, and will produce a large "well-risen" loaf. In this respect the Pusa wheats grown at Pusa gave excellent results; Pusa 111 was placed first in order of merit with Pusa 80-5 next, and these two showed "the qualities which would be expected from a strong Manitoba flour, and there appeared to be no reason why they should not be capable of use in place of normal strong components in a grist intended for ordinary commercial purposes."* Gluten quality and quantity are factors which determine what is known as "strength" in flour. The term strength has been defined as the measure of the capacity of the flour to produce a bold, large-volumed, well-risen loaf [Jago and Jago, 1919]. Since, however, this capacity depends on the various qualities described above, the term "strength" appears undesirable as leading to a generalised indefinite description of that which could be stated with greater precision.

The results of tests with the Sind samples showed that none of them approached in "strength" or general excellence the Pusa samples. The Pusa wheats grown in Sind were, however, superior to the Sind wheats, and among the samples from Sind Pusa 12 and Pusa 114 gave the best bread.

Blending tests with Pusa flours, grown at Pusa, and English flour showed that the mixture Pusa 111-English was distinctly better in all-round quality than a blend of No. 1 Manitoba-English, while the poorest of the Pusa-English blends was distinctly superior to a blend of Choice White Karachi-English. These blends were in the proportion of 50 per cent. Pusa flour to 50 per cent. English. The Sind samples were also tested in blends, but since the baking tests with the straight flours had indicated that the Sind samples were not so strong as the Pusa samples, a different flour was used for blending. Blending tests with strong flours are best carried out with a weak flour in order to ascertain the extent to which the strong flour will carry the weak for commercial purposes. The value of a weak flour, however, is best estimated by seeing the extent to which it can be added to a strong flour without adversely affecting the baking qualities of the mixture. The Sind flours were, therefore, studied in blends by this method and were blended with "Y" reference

* See Appendix, page 407.

flour—" a strong straight run London flour."* In the blending tests with the Sind samples the best results were obtained with Pusa 114, Pusa 12 coming a close second. In both these cases the best loaves were obtained from mixtures containing 40 per cent. of the Pusa flours. The blend with Pusa 111 gave its best loaf when the Pusa flour constituted 15 per cent. of the mixture. The loaf from this mixture " approached in general excellence the loaf from the 40 per cent. blend of Pusa 114."** Pusa 52 and the Sind wheats did not do well in blends. " In each case the addition of 15 per cent. of the Indian flour to the Y reference flour caused slight deterioration which became progressively greater with the higher blends."†

The results of these tests have shown that in one of the new Pusa wheats, No. 111, India possesses a wheat which is equivalent in value to a good Manitoba wheat and which should be of commercial importance as a strong wheat. The report states " It was most attractive in appearance although quite unlike Manitoba, its bright amber colour being in sharp contrast to the typical Manitoba red. It was of excellent milling quality. It appeared to offer no difficulties as regards conditioning treatment, and it seemed distinctly easier to mill than most customary hard wheats. It gave a high yield of flour which was of good appearance (of the hard wheat flour type), and had a remarkably low ash content and high protein content. Like many hard wheat flours it was not a good gasser."‡ In the wheats Pusa 114 and Pusa 12 we have types which, when grown in Sind, possess a high blending value and from all points of view are superior to ordinary Karachi wheat. In spite of the present fall in grain prices, this knowledge comes at an opportune moment when the extended facilities for irrigation in Sind, consequent on the completion of the Sukkur Barrage, will surely lead to an increased production of wheat for export.

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* See Appendix, page 411.

** See Appendix, page 413.

† See Appendix, page 413.

‡ See Appendix, page 413.

Appendix.

A REPORT* ON SIXTEEN SAMPLES OF INDIAN WHEATS GROWN AT PUSA AND SIND, 1929-30.

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The samples were received in bags, packed inside tin-lined boxes, which were labelled 1 to 16 respectively. Nos. 1—6 inclusive were from Pusa, and Nos. 7—16 inclusive from Sind.

Moisture and nitrogen contents on receipt.

Wheat	Sample No.	Moisture content	Total No. (recalculated on a 15 per cent. moisture basis)	Total Protein
	PUSA SET	Per cent.	Per cent.	Per cent.
Pusa . . 4	N. V. 1	10·43	1·92	10·94
12	2	10·95	1·81	10·32
52	3	10·65	1·95	11·12
80-5	4	10·45	2·22	12·64
111	5	10·20	2·23	12·72
114	6	10·71	2·30	13·12
	SIND SET			
Pusa . . 4	N. V. 7	9·45	2·13	12·14
12	8	9·71	1·89	10·78
52	9	9·41	2·04	11·64
80-5	10	9·10	2·06	11·74
111	11	9·29	2·11	12·04
114	12	9·42	2·14	12·20
C. P. H. . 47	13	10·08	1·63	9·29
A. T. . . 38	14	9·81	1·61	9·18
G. S. . . 25	15	9·49	1·69	9·64
Choice White Karachi.	16	9·92	1·54	8·78

* Throughout the report the wheats are referred to under the sample numbers.

The Sind samples as a set were appreciably lower in moisture content than the Pusa. It will be seen that as regards protein content the samples of each set fall distinctly into three groups. The lowest protein contents are those of Nos. 13—16 inclusive of the Sind set. These are just about normal protein contents for Indian wheats as imported commercially into the United Kingdom, and are not much lower than that of No. 2, which is the lowest of the Pusa set. No. 8 ranked by itself in the Sind set and corresponded to Nos. 1 and 3 of Pusa. The third, or highest, group included Nos. 7, 9, 10, 11 and 12 of the Sind series, which were all somewhat lower than the highest group of Pusa, *viz.*, Nos. 4, 5 and 6.

The highest protein contents were astonishingly high for Indian wheat; they were in fact as high as those of good samples of Manitoba wheat.

Appearance of Wheats.

The Pusa set as a whole were very clean. No. 2 differed from the others in appearance. It was like the white component of the so-called Choice White Karachi Wheat, though somewhat deeper in colour and less bleached-looking than commercial White Karachi. On superficial examination it had a striking resemblance to Australian wheat. Some of the grains appeared much more starchy than others. Its grain was of different form from that of the other Pusa samples, being very long and well-filled.

No. 4 perhaps most nearly resembled ordinary Karachi wheat in general appearance. In *colour* it appeared like a cross between White and Red Karachi, but the grains had a bright translucence absent from ordinary Karachi and they were large and plump. Nos. 1, 3 and 5 resembled one another generally. These grains appeared rather larger and leaner than those of No. 4, and they were still deeper in tint, brighter and more corneous. In colour and texture they were most reminiscent of Amber Durum, though not in form—they were plumper and not as long as Durum grains. These three were very attractive samples of wheat. Perhaps 3 had slightly smaller grains and was slightly paler in tint than 1, and 1 than 5. No. 5 contained a little badly discoloured grain. No. 1 contained a few starchy grains, and many of its otherwise characteristic kernels exhibited that curious blackening of the germ end with which we are familiar in, more particularly Plate wheat, but whose nature we do not understand; previous experience has shown that this blackening has no deleterious effect on flour quality.

No. 6 was quite distinct. Its grains were small and plump and quite unlike those of any Indian wheat we have seen. They resembled Manitoba in this respect and, curiously, many of the grains had that characteristic crinkling of the bran coat seen in lower grade Manitobas but, though of an amber shade, it was redder than any other of the Pusa samples.

The Sind set were quite different in appearance from the Pusa. They were very dusty and one or two contained barley and other impurities. At first glance they appeared more like the customary Indian or Persian wheats than did the Pusa samples, having that dull greyish sheen, characteristic of such wheats, which was absent from the Pusa samples. Actually, however, their colour appeared neither like that of Red Karachi nor like that of White, but rather intermediate. The grain was rather like that of Red Karachi in texture—distinctly flinty-looking, but without the clear translucence of the Pusa.

Nos. 7, 9, 10 and 11 were much alike and fairly characterised in appearance by the above remarks. This grouping by appearance was effected before the protein contents were determined, but it will be observed that it is quite in line with the fairly distinct classification of the samples according to protein content.

No. 7 had mostly very large, plump berries and was very flinty. The grains of No. 11, though large, were not so well filled as those of 7. Those of 9 and 10 were appreciably smaller (9 being slightly smaller than 10).

With the exception of 12, the remaining Sind samples (8, 13, 14, 15 and 16) were, to different extents, more starchy than the above-mentioned. No. 16 was a mixed sample of Red and White grain; it resembled a good sample of commercial Karachi wheat. 15 had some starchy grain but most of its berries resembled the "red" of 16, though they had a paler appearance. Nos. 13 and 14 had larger plumper grain than 15. Each (especially 14) contained much starchy grain but most of the berries had a dull, pale, greyish-red appearance. No. 8 was not very different from 14 but its grain had a brighter appearance. It contained much starchy grain and had some resemblance to No. 2 of the Pusa set, though its tint was greyer. Like all the Sind samples it lacked the rich brightness of the Pusa wheats.

Subject to this latter qualification, No. 12 resembled 6 (of the Pusa set) in having a distinctly Manitoba-like appearance. Its grain, however, was larger and better filled than that of No. 6.

Conditioning and Milling.

The Pusa samples did not need dry-cleaning. The Sind samples, which were dusty, were scoured and varying quantities (up to 1·2%) of impurities were extracted.

All the samples were conditioned by additions of cold water at intervals in preparation for milling. The conditioning was gradual, extensive and, as far as possible, carried out uniformly. The Pusa samples were all milled between 6th and 16th August and the Sind between 18th August and 10th September.

Nos. 1, 3, 4 and 5 milled very well indeed. The bran was small but clean, and the reduction stocks lively and yet easy to reduce. Extractions were high. No. 6 seemed slighter, softer; it gave rather larger bran; and the reduction stocks were softer and less lively; extraction slightly lower. No. 2 was less satisfactory in milling properties. It gave a larger bran but its reduction stocks did not reduce very well, and the extraction was relatively low.

With regard to the Sind set as a whole, it would have been better from the milling point of view if these wheats had been conditioned less heavily than the Pusa set. Actually many of them were conditioned much more heavily. This is partly because they were originally drier than the Pusa samples and on the basis of the moisture contents as received, rather heavier conditioning was indicated. As it happened the milling was carried out during a spell of humid weather, and it was found later that the samples had picked up moisture from the atmosphere quite readily. This effect was obvious after the milling of No. 13, and the treatment of the remaining samples Nos. 14 to 16 was lightened somewhat. It was preferred, however, not to make a drastic reduction owing to the fear of invalidating comparison.

Owing to these circumstances it is not safe to draw detailed comparisons of milling behaviour, but on the whole the wheats milled as would have been expected from their appearance. No. 7 was perhaps the hardest wheat of the Sind set and milled very satisfactorily, but these wheats as a whole appeared appreciably softer than the Pusa set and gave less lively reduction stocks. Nos. 7, 9, 10 and 11 were fairly alike and were of the flinty type. Nos. 8, 13 and 16, in sharp contrast to these, were soft, giving bran which was relatively large and tough and starchy reduction stocks, which dressed poorly and flaked badly. Nos. 14 and 15 were unexpectedly "flinty": notwithstanding their high moisture contents they gave rather small clean brans and lively reduction stocks, which in the case of 15 were peculiarly resistant to roll action. No. 12 was fairly distinct and resembled No. 6 of the Pusa set.

The moisture contents of the Mill Feeds, *i.e.*, of the wheats when milled, and Percentage Extraction of Flour (calculated on Total Products) were respectively as follows :—

Sample No.	Moisture content of Mill Feed	Extraction of flour
	Per cent.	Per cent.
1	15·60	72·3
2	16·66	69·0
3	16·52	72·1
4	16·55	72·8
5	16·58	72·7
6	17·09	71·8
7	15·92	71·4
8	16·18	70·6
9	15·51	71·6
10	16·44	73·0
11	17·06	70·6
12	16·79	71·5
13	18·99	69·4
14	17·85	72·8
15	18·51	68·7
16	18·15	68·3

Appearance of Flours.

Of the Pusa flours 1, 3, 4 and 5 had a deep creamy colour of the Manitoba type ; 1, 3 and 5 were alike but 4 was darker and dirtier looking. No. 6 was distinctly whiter than 1, 3 and 5. No. 2 was outstanding ; it had an excellent white colour.

Amongst the Sind set Nos. 7, 9, 10 and 11 were somewhat of the same type as 1, 3, 4 and 5 of the Pusa set though they had a poorer, rather greyer colour. No. 10, however, had easily the poorest colour of all the sixteen samples ; it was a dirty grey. No. 8 was distinct : it had a good white colour and appeared of the same type as No. 2 of the Pusa set ; it was slightly but distinctly poorer (greyer), however, than No. 2. Thus 2 had the finest colour of all sixteen samples.

No. 12 was next in order of whiteness amongst the Sind set, and it was of the same type as No. 6 of the Pusa set. Nos. 14 and 16 were distinct, having a pleasing deep creamy colour (16 was rather poorer than 14). Nos. 13 and 15 were grey-white and, roughly speaking, intermediate in type of colour between 12 and 7, 9 and 11.

Analytical Results on Flours.

All results other than those for moisture content have been recalculated on a 15 per cent. moisture content basis.

Sample No.	Moisture content	Total nitrogen (N)	Total protein (N × 5·7)	Ash	Soluble Extract	Soluble Nitrogen	Soluble P_2O_5	Total P_2O_5	Maltose figure [1]	Total acidity	pH	Buffer Value [2]
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.		
1	14·83	1·80	10·26	·470	4·43	·222	·062	·312	2·3	·45	6·10	·64
2	15·01	1·62	9·24	·561	4·64	·189	·053	·265	1·6	·42	6·19	·65
3	14·66	1·72	9·80	·551	4·87	·222	·048	·219	2·1	·41	6·21	·79
4	15·05	2·14	12·20	·449	4·20	·199	·062	·282	1·8	·45	6·21	·61
5	14·41	2·10	11·97	·414	4·36	·237	·041	·248	1·8	·45	6·02	·79
6	15·06	2·07	11·80	·462	4·19	·260	·038	·244	1·8	·45	6·05	·72
7	14·45	1·90	10·84	·574	4·53	·250	·055	·335	1·8	·44	6·13	·62
8	14·85	1·70	9·69	·594	4·36	·207	·050	·291	1·3	·48	6·19	·75
9	14·23	1·86	10·60	·562	4·09	·207	·043	·327	1·7	·41	6·29	·57
10	15·70	1·91	10·89	·626	4·42	·226	·058	·365	2·0	·45	6·19	·53
11	16·21	1·90	10·84	·564	4·18	·233	·056	·350	1·8	·47	6·11	·63
12	15·88	1·96	11·18	·517	4·18	·294	·038	·297	1·4	·41	5·96	·64
13	16·48	1·44	8·20	·630	4·08	·184	·063	·296	1·5	·40	6·21	·72
14	16·13	1·43	8·15	·604	4·71	·178	·053	·287	1·5	·40	6·29	·76
15	16·52	1·49	8·50	·647	4·54	·196	·055	·270	1·6	·36	6·30	·75
16	16·87	1·34	7·64	·686	4·51	·187	·063	·289	2·0	·34	6·31	·70

[1] The Maltose Figure is the percentage of maltose found after incubating a flour-water mixture at 80°F. for 1 hour. A fig. below 2·2 or 2·3 is indicative of soundness ; *e.g.*, a flour from sprouted wheat may give figs. well above 2·5.

[2] The Buffer Value represents the change in pH due to addition of a fixed amount of lactic acid. Hence the smaller numerically the buffer value, the more highly buffered is the flour.

The order of the nitrogen contents of the flours, of course, follows very closely that of the wheats. The ash contents of the flours do not appear to be significantly affected by percentage *extraction*, *i.e.*, the yield of flour. They are higher in the flours from the more starchy (and hence presumably thicker-coated) wheats. In fact, with one or two exceptions, the ash contents appear strikingly in inverse order to the protein contents, and also, as will be seen, the flours of best baking quality had the lowest ash contents. The ash contents were not reflected in any definite way in the appearances of the flours.

Much the same remarks apply to the Buffer Values which pick out the starchy wheats in the Sind set in an infallible manner, though, curiously, this does not apply to the Pusa set.

The figures for soluble extract, soluble nitrogen, total acidity and maltose appear to be normal, and in the ordinary way would be interpreted as implying soundness of grain.

Gas Production.

In each gas test the following amounts of material were used: 50 grms. flour, 1 grm. (= 2 per cent. of weight of flour) *or* 0·25 grms. (= ½ per cent.) of yeast, 0·625 grm. (= 1¼ per cent.) salt, and 30 c.cs. of water. The temperature of fermentation was maintained at 80°F.

Gas production figures (in c.c.) are given below together with (for purposes of comparison) those of the reference flour marked Y used for blending in some of the baking tests, and of a commercial sample of 1930 crop Choice White Karachi.

2 per cent. Yeast.

Time	PUSA						SIND										1930 Crop C. W. Karachi	Y. Reference Flour
	N.V. 1	N.V. 2	N.V. 3	N.V. 4	N.V. 5	N.V. 6	N.V. 7	N.V. 8	N.V. 9	N.V. 10	N.V. 11	N.V. 12	N.V. 13	N.V. 14	N.V. 15	N.V. 16		
1st hour	39	41	39	40	30	27	30	32	35	36	40	20	31	40	32	33	39	50
2nd ,,	81	79	77	72	61	53	64	67	61	63	65	67	68	70	67	67	69	80
3rd ,,	94	92	89	92	77	64	76	78	71	74	80	76	81	75	71	76	75	96
4th ,,	96	88	101	88	89	59	94	74	91	104	104	77	73	85	83	80	87	111
5th ,,	80	54	53	57	65	36	86	50	61	96	75	30	37	83	69	74	85	117
6th ,,	41	28	21	23	28	19	51	22	26	43	34	19	19	49	28	48	70	89
7th ,,	26	21	17	18	19	19	29	17	17	22	20	15	15	26	19	22	48	61
8th ,,	..	..	..	..	17	13	19	10	10	14	17	12	13	12	12	12	25	46
Total for 24 hours	561	471	449	405	463	383	577	413	431	539	553	383	393	510	444	498	639	927

½ per cent. Yeast.

Time	PUSA						SIND										1930 Crop C. W. Karachi	Y. Reference Flour
	N.V. 1	N.V. 2	N.V. 3	N.V. 4	N.V. 5	N.V. 6	N.V. 7	N.V. 8	N.V. 9	N.V. 10	N.V. 11	N.V. 12	N.V. 13	N.V. 14	N.V. 15	N.V. 16		
1st hour	14	6	9	10	10	10	11	8	10	9	4	6	7	3	5	6	5	..
2nd ,,	16	17	15	10	13	14	15	13	15	17	16	14	11	15	16	16	19	20
3rd ,,	24	27	25	24	26	25	26	27	27	30	28	26	26	29	28	27	33	30
4th ,,	35	33	34	40	40	31	40	41	41	34	41	41	46	43	40	41	42	45
5th ,,	41	47	48	46	43	43	57	51	53	53	51	54	50	52	30	46	45	50
6th ,,	47	53	52	55	52	47	59	50	56	60	60	58	58	55	57	52	45	58
7th ,,	53	50	59	56	56	40	72	66	66	80	76	51	55	62	64	52	48	75
8th ,,	51	43	60	59	52	29	70	43	56	77	70	25	39	59	60	52	53	82
Total for 24 hours	531	470	450	461	461	86	585	407	434	556	555	393	369	459	451	453	592	940

These figures show that none of the sixteen Indian samples are good gassers. Nos. 1, 7, 10, 11 and 14 are best and may be called satisfactory. Nos. 2, 3, 4, 5, 8, 9, 15 and 16 were barely satisfactory since with 2 per cent. yeast gas production fell off during the fifth hour, which is within the period required by certain of these flours for full maturation of the dough.

All those just detailed maintained gassing sufficiently well over eight hours with $\frac{1}{2}$ per cent. yeast.

Nos. 6, 12 and 13 are definitely poor gassers. With $\frac{1}{2}$ per cent. yeast, gassing fell off before the end of the eighth hour.

The 1930 Crop Commercial Karachi included was a satisfactory gasser, and Y, the Commercial London straight run flour made from a mixture of wheats, was a very good gasser.

It should perhaps be pointed out that inadequate gas production, though commonly characteristic of Indian wheats, is not necessarily a serious defect from the commercial point of view in a wheat such as Indian which is used only in blends with other wheats. It is sometimes a feature, for example, of high grade Manitobas, and it may be remedied in commercial practice by appropriate blending with other wheats before milling.

In our baking tests the difficulty was overcome through the addition of 0·1 per cent. malt extract and 0·05 per cent. ammonium phosphate to each dough. Such addition ensures adequate gas production throughout the period of fermentation normally required.

Baking Tests.

The *six Pusa Samples* were first baked on 21st August (together), in each case using $3\frac{1}{4}$, 4, $4\frac{3}{4}$ and $5\frac{1}{2}$ hours' fermentation (including final proof) respectively. Doughs were made at intervals of $\frac{3}{4}$ hour apart so that 24 (tinned) loaves went to the oven together. 2 per cent. yeast, $1\frac{1}{4}$ per cent. salt and a fermentation temperature of 80° F. were used. Each dough was made with liquor at the rate of sixteen gallons per sack and 0·1 per cent. malt extract and 0·05 per cent. ammonium phosphate was incorporated.

Doughs.—At doughmaking Nos. 4 and 5 gave the best handling doughs. They were of very good body with very good spring and very good elasticity. No. 1 was of fairly good body having fairly good spring and good elasticity. No. 3 was of fairly good body; it had fair spring and good elasticity. No. 2 was of very fair body and had fair spring, and good elasticity. No. 6 was of fair body; it had very fair spring and very fair elasticity.

In the fermentation boxes all doughs showed very good rises though perhaps 2 and 6 were slightly poorer than the others. Nos. 4 and 5 had bold tops; the others were fairly bold, 6 being rather flatter than the others.

Nos. 4 and 5 were consistently the best handling doughs throughout the various stages of fermentation. Nos. 2, 3 and 6 tended to fall off unduly towards the end of the longer periods.

When moulded all the $3\frac{1}{4}$ hour doughs were "green" or under-fermented. They were appreciably better at 4 and all fully ripe at $4\frac{3}{4}$ hours. At $5\frac{1}{2}$ hours Nos. 4 and 5 (5 in particular) were outstandingly the best, being very tough and elastic with very good spring. Nos. 2, 3 and 6 were obviously overworked and 1 was on the border line.

Loaves.—Of the No. 1 loaves the choice lay between 4 and $4\frac{3}{4}$ hours. Possibly the better was the $4\frac{3}{4}$ hour loaf which had very good oven spring and was a large loaf of very good outside appearance and crust. It had crumb which was fairly close and even in grain, well-piled and of very good texture and spring with a good pale creamy colour. The $5\frac{1}{2}$ hour loaf was good and did not show serious signs of over-fermentation.

The best loaf of the No. 2 set was that at 4 hours. It had very good oven spring and volume, good outside appearance and crust, and good crumb which was close and even in grain,

well-piled and of good texture and spring with a good creamy colour and good bloom. The fermentation tolerance of this sample was much more sharply defined than that of No. 1. The $4\frac{3}{4}$-hour loaf was distinctly poorer than that at 4 hours.

Again with No. 3 the best loaf was thrown at 4 hours. It had very good oven spring and volume, good outside appearance and crust. Its crumb was close and even in grain, well-piled, of very good spring and texture with a pale creamy white colour. Tolerance was not quite so sharply defined as with No. 2; the $4\frac{3}{4}$-hour loaf was only slightly inferior to the 4 hour, but that at $5\frac{1}{2}$ hours was markedly inferior.

Like No. 1, No. 4 had an extended tolerance. It gave good bread throughout the range tested. The best loaf was thrown at $4\frac{3}{4}$ hours. It had very good oven spring, good outside appearance and crust, and its crumb was close and even in grain, well-piled, of very good spring and texture, and of a pale grey white colour. No. 5 also had an extended tolerance. All the loaves were good and the best, at $4\frac{3}{4}$ hours, was magnificent. It had excellent oven spring, volume and outside appearance and crust. Its crumb was close and even in grain, of very good pile, spring and texture, and of excellent colour—a pale creamy white with very good bloom.

No. 6, on the other hand, had limited and fairly sharply defined tolerance. The best loaf, at $3\frac{1}{4}$ hours, had very good oven spring and volume, rather reddish crust. Its crumb was slightly open but even in grain, of very good pile, spring and texture, with a good creamy white colour. The 4-hour loaf was similar in oven spring and volume, but much paler in crust, and slightly but distinctly inferior in crumb qualities. It was slightly overworked.

In general terms, Nos. 1 and 5 had the most extended tolerance to fermentation with No. 4 as a close runner-up. Nos. 3 and 2 were next, in that order. No. 6 had the most limited and sharply defined tolerance. As regards dough handling properties the order was: 5 best, 4 (nearly equal to 5), 1, 3, 2, 6.

Order of merit *amongst the best loaves* of each set was as follows: 5, 4, 1, 3, 2, 6. No. 5 was the best loaf. There was little to choose between 1 and 3. Even the poorest loaf (No. 6) was wonderfully good bread for Indian. In fact, any one of the six loaves would have done credit in all characters to a normal commercial straight run flour of the London area. All were of large volume which is unusual in loaves made from Indian wheats.

The best of these Indian flours showed the qualities, both in dough and bread, which would be expected from a strong Manitoba flour, and there appeared to be no reason why they should not be capable of use in place of normal strong components in a grist intended for ordinary commercial purposes.

Blending Tests with Pusa Flour.

It will be seen that the above conclusions were substantially confirmed by results on a series of blends of English flour with each of the Indian flours.

The following series was baked on 28th August:—

1. 50 per cent. English *plus* 50 per cent. N. V. 1
2. 50 per cent. English *plus* 50 per cent. N. V. 2.
3. 50 per cent. English *plus* 50 per cent. N. V. 3.
4. 50 per cent. English *plus* 50 per cent. N. V. 4.
5. 50 per cent. English *plus* 50 per cent. N. V. 5.
6. 50 per cent. English *plus* 50 per cent. N. V. 6.

W. 50 per cent. English *plus* 50 per cent. 1930 Crop C. W. Karachi (N. C. 40).

X. 50 per cent. English *plus* 50 per cent. No. 1 Manitoba.

Y. A typical strong commercial London straight run flour made from a mixture of wheats.

All doughs were made up with sixteen gallons liquor per sack, 2 per cent. yeast, and were given 4 hours' fermentation (including final proof at 80° F.). Ammonium phosphate and malt extract was added to each.

Doughs.—At doughmaking, all the samples were fairly tough with a slightly clay-like feel. Nos. 1 and 3 had fairly good spring and elasticity. No. 2 had good, 4, 5 and X very good spring and elasticity, whilst 6 and W were only very fair in this respect (W was slightly poorer than 6). Y was fairly elastic with good spring.

In the boxes all samples had good rises. X was the best in extent of rise and had the boldest top. Nos. 4 and 5 were next best, and 1 and 2 also were bold. Nos. 3, 6, W and Y had rather flat tops.

X moulded tightly with good spring and elasticity as did 4 and 5 which were only slightly inferior to X. W was poor being tender and rather short. Nos. 3 and 6 were slightly better than W. The others were intermediate between these, and 4 and 5.

On the tray at final proof, X was boldest; 4 and 5 were also bold; 3, 6 and W and Y showed considerable flow. The others flowed more or less and were intermediate between these two groups.

Loaves.—Y had good oven spring and volume, but was rather a flat loaf, of very good outside appearance and crust. Its crumb was close and even in grain, well-piled, of very good spring and texture, and very good pale grey white colour.

X had very good oven spring and volume. It was a very bold loaf of very good outside appearance and crust, and had crumb, close and even in grain, of good pile, very good spring and texture and pale grey white colour.

No. 1 was equal to X in respect of oven spring, volume and boldness, but had a rather broken crust. Its crumb was open but even in grain, and soft, being of fairly good spring, good pile and texture with a pale creamy colour.

No. 2 resembled Y in volume and oven spring, but was slightly flatter still, and its crust was broken. It was slightly more open than No. 1 in grain of crumb which was of fairly good spring, good pile and texture, with a very dark creamy white colour.

No. 3 had fairly good volume and very fair oven spring. It was rather a flat loaf, of broken crust. Its crumb was closer in grain than, but otherwise similar to, that of Nos. 1 and 2.

No. 4 had slightly better oven spring and volume than No. 1 and X. It was a bold loaf of good outside appearance and crust, but its crumb was rather coarse and open in grain though of good spring, pile and texture, with a pale creamy colour.

No. 5 had excellent oven spring and volume. It was a fine, well-developed loaf with crumb rather open in grain but of very good spring, good pile and texture, and good pale creamy colour.

No. 6 resembled 3 in general outside appearance. It had a beautifully finely grained crumb which, however, was slightly cheesey and of only fairly good spring, and had a deep creamy colour.

W had fairly good volume and oven spring, being fairly bold but it had a badly torn crust, and a very finely grained honeycomb type of crumb, which had only fair spring, fairly good pile and texture with a deep creamy colour.

In general the order of merit amongst the six Pusa blends was: 5, 4, 1, 6, with 2 and 3 poorest.

The best of these (5) was even distinctly better in all-round quality than the Manitoba-English mixture, X or the commercial straight run, Y. The poorest were distinctly inferior to these latter but, at the same time, appreciably better than the blend containing the 1930 Crop Choice White Karachi flour, W.

Baking Tests on the Sind Samples.

The ten sind samples were first baked on the 24th September in two sets which respectively included Nos. 7, 8, 9, 10 and 11 in the first, and Nos. 12, 13, 14, 15 and 16 in the second.

In every case four doughs were made at intervals of ¾ hour so that the doughs went to the oven together representing 3¼, 4, 4¾ and 5½ hours' fermentation respectively. The procedure was exactly as that described for the Pusa samples. Each dough was made with 16 gallons of liquor per sack.

Doughs.—Of *the first set* at doughmaking Nos. 7 and 10 were tough and rather clay-like having only fair spring and elasticity. Nos. 8 and 9 were rather more tender, but had good elasticity and spring ; 11 was, roughly speaking, intermediate between these two pairs.

In the fermentation boxes all doughs showed similar good rises up to the second knock-back except No. 8 which was slightly poorer. At scaling time, all the 3¼ hour doughs showed similar very good rises, though 8 was rather poorer than the others. Of the 4-hour doughs all, except 8 which was slightly behind, had very good rises but 7, 10 and 11 were tearing ; 9 was tearing slightly ; 8 showed no signs of tearing and had the boldest top. At 4¾ hours 7, 10 and 11 had very good rises, but 10 and 11, were badly torn whereas 7 had a good bold top and was only tearing slightly. No. 9 had only a fairly good rise and was tearing slightly. No. 8 had a poor rise and showed no tearing. All the 5½-hour doughs had fallen off badly, 8 and 9 being poorest.

Nos. 7 and 10 were tough and short at moulding (especially 10) ; 8 and 9 moulded tightly with good spring and elasticity ; 11 was intermediate but rather more like 7 and 10.

In each case the 3¼-hour doughs were fully ripe, overripeness being noticeable even at 4 hours, though 7, 10 and 11 (especially 10) maintained good handling properties best.

Loaves.—At 3¼ hours No. 7 had very good volume, and oven spring, and very good outside appearance and crust, with a good face. Its crumb was close and even in grain, well-piled, of very good spring and texture, with a good pale creamy colour. The 4-hour loaf was distinctly inferior in all characters whilst the longer-period loaves were badly down.

No. 8 at 3¼ hours had excellent volume and oven spring. It was a very bold loaf with very good outside appearance and crust and large double face. Its crumb was very close and even in grain, well-piled and of very good spring and texture. It had an excellent creamy white colour with a fine bloom. All the loaves of sample 8 were markedly inferior.

Again with No. 9, 4 hours' fermentation and oven caused a very sharp falling off in the bread. The 3¼-hour loaf had very good volume and oven spring and, except for slight tearing of the crust, a good outside appearance. Its crumb resembled that of No. 7 at 3¼ hours.

No. 10 at 3¼ hours had good oven spring and volume but a rather pale and torn crust and broken face. Its crumb was fairly close and even in grain, of fairly good spring, good pile and texture, and had a pale grey white colour with very good bloom. The 4-hour loaf was not markedly inferior but its crust was duller and its crumb rather more open in grain and tougher. At 4¾ hours it showed distinct falling off in all characters whilst the 5½-hour loaf was badly down.

The 3¼-hour loaf of No. 11 resembled closely those of Nos. 7 and 9. At 4 hours it had deteriorated little except that its crumb had become tough and holey and dull in colour. A sharp fall occurred at 4¾ hours.

Thus with each of the Sind blends the best loaf was thrown at 3¼ hours, but whereas 10 had the greatest tolerance to fermentation (still giving tolerable bread at 4¾ hours), 8 and 9 had a very limited tolerance (8 being poorest of all). Nos. 7 and 11 were second and third respectively in order of decreasing tolerance, but both were distinctly behind 10.

On the other hand of the 3¼ hour loaves, 8 was outstandingly the best; 7 and 11 ranked next and, not far behind came 9; 10 was easily poorest.

Thus a summarised comparison of these five Sind samples is somewhat difficult though clearly none of them approached in "strength" or general excellence the poorest of the Pusa samples. No. 8 gave the best bread, and 8 and 9 gave the best handling doughs though they did not rise well during fermentation.

On the other hand, 8 and 9 had the most limited fermentation tolerance of these samples.

With *the second set of Sind flours* was included the 3¼-hour test on No. 8 of the first set for purposes of comparison.

Doughs.—At doughmaking 8 and 12 were alike fairly tough with very good spring and elasticity. No. 16 was tough with fairly good spring and elasticity. Nos. 13, 14 and 15 were fairly tough, short and clay-like, 13 being slightly better than the other two.

All doughs worked well up to the second knock-back, and all the 3¼-hour doughs had similar very good rises. The same was true at 4 hours but 14 was tearing slightly. The longest doughs all showed very good rises, except 12 and 13 which showed only fair rises, but all tore badly.

At 3¼ hours, 8, 12 and 16 moulded fairly tightly with good spring and elasticity (16 was slightly poorer than 8 and 12); 14 and 15 were tough, short and rather lifeless; 13 was intermediate between these extremes. Much the same remarks applied to the 4-hour doughs except that 14 was very short. At the longer periods all the doughs were over-ripe though 14, 15 and 16 retained their handling properties better than did 12 and 13.

Loaves.—Nos. 12 and 8, at 3¼ hours, were much alike. They had excellent volume and oven spring, being large bold loaves of very good outside appearance and crust, and large face. Their crumb was close and even in grain, well-piled and of very good spring and texture, with a very good creamy white colour (12 was rather paler than 8). No. 12 at 4 hours was only inferior in that its crust was more flinty and paler, and that it had a rather poorer crumb colour, but 4¾ hours brought a sharp fall. No. 13 at 3¼ hours had very good volume and oven spring, and a good face, but rather flinty, pale crust. It had crumb, close and even in grain, of good pile and texture but rather poor spring ("Corky" crumb) with a yellowish colour. The 4-hour loaf was similar in oven spring and volume, but had a somewhat slate-coloured crust and a poorer face. Its crumb was slightly softer and paler but rather cheesey. The optimum loaf was ndicated between 3¼ and 4 hours: 4¾ hours and over produced poor bread.

In the case of sample 14, the 4-hour loaf was distinctly better all-round than the 3¼-hour. It had very good oven spring and volume, was of good outside appearance and crust with a very good face, and had crumb of the fine honeycomb type of grain, well-piled, of very good spring and texture with a good but distinctly yellowish colour. At 4¾ hours the loaf was similar but paler both in outside appearance and in colour of crumb. The best loaf would have been thrown between 4 and 4¾ hours. The 5¼-hour loaf was markedly inferior in all characters.

Again with sample 15, a better loaf was thrown at 4 hours than at 3¼. It had very good oven spring and volume, but a rather biscuity crust and a somewhat crumb of the fairly finely grained honeycomb type which had good pile and texture, but only fairly good spring, and a deep creamy colour. The 4¾-hour loaf was similar but had rather paler crust and poor spring, and paler colour of crumb. As with No. 14 the optimum was suggested between 4 and 4¾ hours, and 5¼ hours brought marked deterioration.

No. 16, at 3¼ hours, had very good oven spring and volume and was of very good outside appearance and crust with a large face. Its crumb was close and even in grain, well-piled, of very good spring and texture, with a rather yellowish colour. At 4 hours it was similar but paler in crust, and closer in grain of crumb which was of poorer spring, but better colour. The best loaf was indicated between 3¼ and 4 hours. The 4¾-hour loaf, however, was only slightly inferior (in respect of spring of crumb) to the 4-hour, but 5½-hours marked a definite drop.

Thus 14, 15 and 16 had quite extended fermentation tolerance, resembling in this respect No. 10. No. 13 had a fairly, and 12 a very, limited tolerance; 12 thus resembled 8 as it did, moreover, in bread quality as well as in dough handling.

As with the first set of Sind flours, summarised comparison is not easy because although 14, 15 and 16 had the longest fermentation tolerance, yet 12, 16 and perhaps 13 gave the best handling doughs. On the other hand, 12 gave far and away the best bread of these samples. There was relatively little to choose between the best loaves of each of the other samples though perhaps 15 was the poorest.

With the exception of No. 12, this second set appeared on the whole to be definitely inferior to the first set of Sind samples. There was a definite suggestion of ordinary Karachi-wheat quality about the crumb of the bread.

Blending Tests with Sind Samples.

The blending properties of the Sind flours were now compared through a series of baking tests on blends of each flour to the extent of 15 per cent., 25 per cent., and 40 per cent. respectively with "Y" reference flour. This is a different treatment from that accorded to the Pusa samples. The baking tests already described left no doubt that with respect to "strength" the Sind samples were in a different category from the Pusa. Blending tests on a strong flour are best carried out with the help of a weak flour, so that an idea can be obtained of how the "strong" flour will "carry" weakness for commercial blending purposes. The usefulness of a weaker flour, however, is judged by seeing to what extent it can be added to a good average blend without adversely affecting the quality of the latter: if its incorporation produces some improvement, so much the better.

On the whole, the Sind flours appeared of such a character as to be best studied by this latter method. "Y" reference flour was very suitable for the purpose: it is quite a strong, straight run London flour, unbleached and untreated, made from the following grist:—

	Per cent.
No. 1 Manitoba	15
No. 3 „	10
No. 4 „	10
No. 5 „	10
No. 6 „	15
No. 2 Hard Winter	7½
Rosafe Plate	7½
Australian	10
French	15
	100

It will be seen that it contains a high proportion of " strong " constituents and also that it contains no Indian wheat.

It is a good gasser and the possibility of inadequate gas production is entirely ruled out of consideration in the baking tests to be described.

In order to link up the Sind with the Pusa flours, the poorest of the Pusa samples (No. 6) was included in the series.

Doughs.—All doughs (cobs) were made with liquor at the rate of sixteen gallons per sack. 2 per cent. yeast and 4 hours' fermentation at 80° F. were used, and 0·1 per cent. malt extract and 0·05 per cent. ammonium phosphate was added to each dough.

At doughmaking " Y " flour alone was fairly tough and had fairly good spring and elasticity. The blend containing 15 per cent. No. 6 was fairly tough with good spring and elasticity; the 25 per cent. and 40 per cent. blends were similar but slightly tougher. The blends of Nos. 8, 11 and 12 were very like those of No. 6.

In the case of 10, the 15 per cent. blend was fairly tough with fairly good spring and elasticity; the 25 per cent. and 40 per cent. blends were tougher and rather shorter.

With No. 7 the 15 per cent. blend was fairly tough with good spring and elasticity : 25 per cent. was rather tougher but 40 per cent. was intermediate.

In the case of No. 15 and No. 16, the 15 per cent. blends were fairly tough with fairly good spring and elasticity, the 25 per cent. was rather tougher but the 40 per cent. was intermediate.

With Nos. 9, 13 and 14, the 15 per cent. blends were fairly tough (that of No. 9 was rather tender) with fair spring and elasticity. With further increasing content of Indian flour the blends became tougher and acquired a clay-like feel.

All doughs worked well throughout the various stages of fermentation and, broadly speaking, the differences described persisted. As fermentation proceeded the blends appeared to " bind " rather more than the Y flour alone. This effect was most marked in each case at 25 per cent.

In the boxes all doughs showed similar very good rises and had fairly bold tops, and all moulded tightly, the differences described having persisted.

On the tray at final proof no significant differences in stability were noticed.

Loaves.—The loaf from Y flour alone had very good volume and even spring, was of very good outside appearance and crust; and had crumb, fairly close and even in grain, of good spring, pile and texture with a pale grey white colour.

Steady improvement followed the addition of No. 6 up to 40 per cent.. The 40 per cent. blend had excellent oven spring, volume and outside appearance and crust. Its crumb was peculiarly tough but well-developed. It was rather open but even in grain (though slightly holey) of good spring, pile and texture with a pale creamy white colour.

No. 12 appeared distinctly the best of the Sind samples from the blending point of view. Steady improvement took place up to 40 per cent. The 40 per cent. loaf was of excellent volume and oven spring. It had a very close even grain of crumb which was well-piled, of very good spring and texture with an excellent pale creamy colour.

No. 8 was not markedly inferior to 12. Again progressive improvement occurred as far as 40 per cent. at which point the loaf had very good oven spring and volume, and crumb close and even in grain, well-piled, of very good spring and texture with a good pale grey white colour.

Some considerable way behind these came No. 10 in order of blending merit—rather unexpectedly in view of its bread quality when baked alone. Addition of No. 10 up to 40 per cent. slightly improved Y flour.

The remaining samples gave best results when added in smaller proportions than 40 per cent. With Nos. 7 and 15, 25 per cent. was the best blend, and the resulting loaves were distinctly better all-round than that from Y flour alone. With No. 11 the 25 per cent. was slightly inferior to the 15 per cent. loaf which, however, was very fine, and was not only superior to that from Y flour alone, but approached in general excellence the loaf from the 40 per cent. blend of No. 12.

The remaining samples (Nos. 9, 13, 14 and 16) were distinctly poorer. In each case the addition of 15 per cent. of the Indian flour to the Y reference flour caused slight deterioration which became progressively greater with the higher blends. The order of merit was: Nos. 9, 13, 16, 14, 14 being the poorest.

Summmary and Conclusions.

Wide variations in type and quality have been encountered amongst the sixteen samples, so much so, that the extremes almost might be said to typify " strength " and " weakness ".

On the whole, the Pusa samples appeared of much higher quality than the Sind though it is perhaps not justifiable to make a clean-cut division.

Certainly the finest samples were amongst the Pusa set and of these No. 5 was outstanding. It appeared to be equivalent in value to a good Manitoba wheat, and we have no hesitation in saying that if No. 5 can be successfully grown in India, it should be of commercial importance as a strong wheat. It was most attractive in appearance although quite unlike Manitoba, its bright amber colour being in sharp contrast to the typical Manitoba red. It was of excellent milling quality. It appeared to offer no difficulties as regards conditioning treatment, and it seemed distinctly easier to mill than most customary hard wheats. It gave a high yield of flour which was of good appearance (of the hard wheat flour type), and had a remarkably low ash content and high protein content. Like many hard wheat flours it was not a good gasser.

In the bakehouse it gave a dough of excellent handling qualities, with the wide fermentation tolerance of a strong flour, and excellent bread. It appeared to have the blending value of a strong flour.

No. 4 was nearly as good, generally, as No. 5. Next in order of merit but a long way behind came No. 1.

A wheat of a weaker type may on account of certain qualities be of just as much commercial importance as a strong wheat. In this connection certain of the Sind samples appear to deserve mention. As relatively weak wheats Nos. 8 and 12 appeared to have high blending value. They milled well as relatively soft wheats, and gave good white flours. No. 8 had a normal protein content for soft flours, but 12 had comparatively high protein content. It is true that they were not good gassers, and they had the restricted fermentation tolerance of weak flours, but they gave dough of good handling qualities, from the blending point of view, and they appeared to fine advantage in the bread. From all points of view these were superior to ordinary Karachi wheat as commercially used for blending in this country.

Many of the remaining samples may be said to fall between two stools in the sense that they possess neither the degree of strength of the best Pusa samples, nor the value of weakness for blending purposes of the best Sind samples.

The poorest samples are fairly definitely Nos. 13, 14 and 16, which are certainly of no more value than ordinary commercial Karachi wheat.

Any further attempt to rank the samples in order of merit must be tentatively made, and then in connection with the Sind samples alone. Nos. 12 and 8 are best left apart for reasons discussed.

The order of merit of the remaining Sind samples might be as follows :

10, 7, 11, 15, 9, 16, 13 and 14.

Nos. 13 and 14 are distinctly poorest ; perhaps a fairly sharp dividing line might be drawn between Nos. 9 and 16.

The extensive experimental work involved in the preparation of this report has been the work of several members of the staff of the Research Association, in particular of Dr. C. R. Jones, Mr. R. H. Carter, Dr. P. Halton and the baker, Mr. W. E. Spencer. Messrs. A. Lucy and F. W. Newman rendered some assistance in the analytical work and in the milling of the samples.

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ABSTRACT

Chromosome Behavior and Pollen Production in the Potato. A. E. LONGLEY. *J. Agric. Res.* **41**, 857—888.

This paper presents a study of the number and meiotic behavior of chromosomes in tuber-bearing forms of Solanum.

Ten wild species of potato were found to have 12, 18, 24 or 36 as their haploid chromosome number. Two species, *Solanum commersonii* and *S. cardiophyllum* f. *coyoacanum*, with 18 as their haploid chromosome number, have meiotic irregularities in their pollen mother cells similar to those found in a known F_1 hybrid of *S. fendleri* × *S. chacoense*, suggesting that these two wild species are natural hybrids.

Three cultivated varieties of *Solanum tuberosum* grown in South America have 12 as their haploid chromosome number.

Thirty-seven cultivated varieties of *Solanum tuberosum* grown in the United States have 24 as their haploid chromosome number.

The meiotic behavior of the 24-chromosome *Solanum tuberosum* varies from regular in a few to extremely irregular in many of the varieties.

Only the few varieties with a regular chromosome behavior produce an appreciable amount of pollen; varieties with an irregular chromosome behavior produce practically no pollen. Unfruitfulness in potatoes would therefore seem to be due to abnormal chromosome behavior at the time of pollen formation.

The chromosome behavior of a few selected individuals seemed to be affected to some degree by environmental changes.

The number and behavior of the chromosomes in our cultivated potato varieties suggest that they have a mixed ancestry, and that the ancestors are to be found not in a single wild species but in two or more.

Author's Summary.

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REVIEW

The Coconut Moth in Fiji. By J. D. Tothill, T. H. C. Taylor, and R. W. Paine. Pp. vii + 269, 119 figs., 34 tab. (Imperial Institute of Entomology, London, 1930.) Price 31*s.* 6*d.* net.

This handsomely-produced volume is devoted to an account of work done in controlling a small Zygaenid Moth, *Levuana iridescens*, Bethune-Baker 1906, which was found to be destroying the leaves of coco-palms in the Fiji Islands to such an extent as to reduce the production of copra, and even to imperil the industry altogether. In the year 1924 things had come to such a pass that a prize of five thousand pounds was offered to anyone who could indicate a remedy ; this offer, however, was shortly afterwards withdrawn on the appointment of a staff of three entomologists to institute a campaign against this pest. The present volume gives an account of their investigation of this one insect from all points of view—systematic, bionomic and economic—and that such investigations provide material for a whole book may serve to show the scale on which these were carried out. A summary of this would be of little use to Entomologists, who should obtain it and read it for themselves, and of less interest to those without knowledge of modern entomological technique. Suffice it to say that, at the time this book was written (in January 1929), the introduction of parasitic control had proved so successful that there had been no new outbreak of the pest during the preceding three years, and that this successful result was due primarily to the broad-minded policy of sending one of the entomological staff to the Malay States to search for and transfer to Fiji parasites of another Zygaenid moth attacking coconut palms in Malaya.

Of special interest to the Entomologist in India are the accounts of *Artona catoxantha*, Hampson 1893 (pp. 210-216), and of *A. albicilia*, Hampson 1900 (pp. 223-225), both of which occur within Indian limits, and also of *Trichogrammatoidea nana*, Zehntner (pp. 244-248), a Javanese egg-parasite of *Diatraea*, *Chilo*, *Scirpophaga*, *Schoenobius* and *Argyroploce*, which would seem worth further investigation as a parasite of cane-borers in India. [T. B. F.]

ORIGINAL ARTICLES.

A CYTOLOGICAL STUDY OF *CAPSICUM ANNUUM*.

BY

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(Received for publication on the 13th March, 1931.)

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(With Plates XXXIII to XXXVII and one text-figure.)

(1) INTRODUCTION.

The chromosome number can only be determined with complete certainty when the whole cycle of the chromosomes is taken into account, including comparisons of the gametic with zygotic number and the number seen in somatic divisions particularly at the early stages. A controversy has arisen as to the chromosome number in *Capsicum annuum*. Kostoff [1926] worked out the chromosome number in 4 varieties of *Capsicum annuum*, viz., *Capsicum annuum chilense*, *C. annuum grossum*, *C. annuum microcarpum*, *C. annuum nigrum*, and found that the haploid number was 6. In all varieties studied, especially in *Capsicum annuum chilense*, he found that one pair of chromosome was considerably larger than the others and was usually on the periphery of the equatorial plate. De Vilmorin and Simonent [1927], in studying the chromosome number of various members of Solanaceae

family, counted 12 chromosomes in the pollen mother cells of *Capsicum annuum* L. var. *Hort.* and *Capsicum annuum* L. Huskins and Lacour [1930] made chromosome counts in eight varieties of *Capsicum annuum* and two varieties of *Capsicum baccatum*. In each case the chromosome number was found to be twelve. They remark that Kostoff [1926] states the chromosome number to be twelve at metaphase, and that his microphotographs show this number of bivalents. On the other hand, his figures showing six chromosomes distributed to either pole are not convincing. They conclude that the chromosome number is equal to 12. They have also confined their studies to pollen mother cells.

In view of the fact that *Capsicum annuum* is a species which has many advantages for genetical study, and that genetical work is in progress at this Institute [Shaw, 1929 and 1930] with the species, an investigation has been carried out to ascertain the right number of chromosomes in this species. Previous investigators have made counts only in the pollen mother cells; in this investigation the study of chromosome numbers was extended to the root tips of *Capsicum annuum* in order to determine the diploid number. During the course of this investigation some peculiarities were noticed in the Somatic Mitosis, firstly as regards the behaviour of the nucleolus which appears to play a more active and important part in the metabolism of the nucleus than has hitherto been assumed, and secondly the mode of the formation of the cell plate. These have been described in some detail in the present paper.

The pollen mother cells were also examined by the smear method in order to find out the haploid number and confirm the results obtained from the root tips.

(2) Diploid Number.

Material and Methods.

Seed of *Capsicum annuum* Type 36 and Type 40 isolated at Pusa were kept for germination in sterilised petri-dishes. They germinated after four days. As the root tips were very small, the germinated seeds were fixed as such at about 12-45 P.M., this being the time at which divisions were found to be most abundant. Four fixatives were tried:—(1) Carnoy's Fluid (glacial acetic acid 1 part, absolute alcohol 6 parts, chloroform 3 parts), (2) Shaffner's weak formula (chromic acid 3 gms., glacial acetic acid 1 c.c., H_2O distilled 100 c.c.), (3) chromo-osmic-acetic (10 per cent. chromic acid 1 c.c., 10 per cent. acetic acid 10 c.c., 2 per cent. osmic acid in 2 per cent. chromic acid 7 to 8 c.c., maltose 0·2 gr.), (4) Allen's modification of Bouin's fluid. (Picric acid, saturated solution in distilled H_2O, 75 parts, formalin 15 parts, glacial acetic acid 10 parts, urea 1 part.) The first fixative caused too much shrinkage, the second one fixed only on the periphery, and the third caused

undesirable blackening which could not be easily bleached. The fourth Allen's modifications of Bouin's fluid was found most suitable. The material was kept in the fixative for 24 hours and then washed in grades of alcohol—20 per cent. by 5 to 90 per cent. and absolute. Addition of lithium carbonate solution was not found essential. It was interesting to note that the root tips increased in length a good deal in this fixative. Material was cleared in grades of xylol and embedded in 56 c.—58 c. paraffin. Sections 10 μ thick were cut and stained according to Haidenhain's Iron Alum Haematoxylin method. Two hours in 4 per cent. iron alum solution, followed by the same interval in ½ per cent. aqueous haematoxylin solution, was found suitable for getting the right stain. Orange-G in clove oil was used as the plasma stain.

General Morphology of the Cell.

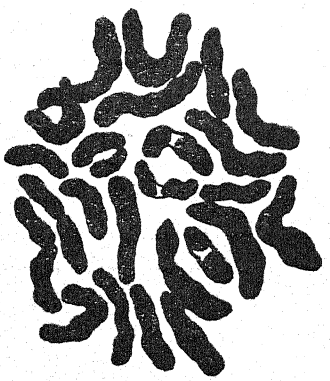
The cells are subject to considerable fluctuations of size and shape, especially in a growing region such as that of the root tip which is the subject of the present cytological studies. The cells in transverse section are irregularly round, while in the longitudinal section, they have a somewhat rectangular appearance, *i.e.*, the cells are elongated along the longitudinal axis of the root tip. This point has been emphasised because in the rapidly elongating tissue the cell divisions commonly take place in the transverse plane and spindle appears in the longitudinal plane of the cell. The division plane of some cells is sometimes changed due to the influence of various tropisms which disturb the normal polarity of the spindle, etc. Prophases and Metaphases are clear in transverse section, while Anaphases and Telophases are common in longitudinal sections.

Each cell is rich in cytoplasm of a fine recticulate nature. The cell walls are quite thin in the young cells but grow thicker in the older ones. The nucleus ordinarily occupies a central position in the cell and is approximately spherical in shape. It is surrounded by a distinct nuclear membrane which is stained darker than the nucleoplasm within it and the cytoplasm outside it, and it appears to be a definite morphological structure belonging to the nucleus. Inside the nuclear membrane there is (1) the linin network which is very very faint in outline, and (2) the small chromatin granules which are irregularly scattered and take up a dark stain. There is usually one nucleolus in each nucleus but in some two or three are also present. Classification of nucleoli into plasomosomes or the true nucleoli and karysomes or the chromatin nuclei, as proposed by Montgomery [1899] and Ogata [1883], on the basis that former do not contribute to the formation of chromosomes and are oxyphilic and latter contribute towards the formation of chromosomes and are basophilic, does not seem to be tenable. The nucleoli are basophilic and contribute to the formation of chromosomes as can be seen in *Capsicum* and is the case in most

other plants which have been examined cytologically. The nucleolus when it is single is large in size, but when two or more are to be found there is a proportionate decrease in their size. There is a definite envelope surrounding the nucleolus which has a different consistency and a staining reaction to the nucleolus. Reference to the presence of such a membrane surrounding the nucleolus in plant cells has been made by Mitzkewitsch [1898] and others. In some cases the nucleolus appears to be homogeneous throughout, but in the majority of nuclei it possesses one or more vacuolar spaces filled with a substance which appears to differ from the rest of nucleolus. The vacuolate structure of nucleoli appears to be very common and was first noticed in vegetable cells by Schleiden [1849], and has later on been reported by various workers. The nucleolus is surrounded by a clear space. Nemec [1908] attributes the hyaline appearance of this space to the fact that chromatin granules are absent, while Wager [1904] thinks that it indicates the beginning of transference of the nucleolar material to the nuclear thread. No threads as described by Wager [1904] are visible suspending the nucleolus to the peripheral wall of the nucleus. A number of nucleoli displaced from the nuclear cavity were examined, but no such threads drawn from the nucleolus as shown in Fig. 6 (*a*) of Plate 5 in Wager's paper on *phaseolus* could be seen. The nucleolus lies free in a clear cavity, which is probably filled with some colourless fluid [Plate XXXIII, Fig. 1].

Outline of Mitosis.

The process of Somatic Mitosis begins with the appearance of numerous small delicate threads formed from the reticulum. They join together giving rise to a discontinuous spireme, which resolves itself into definite paired chromosomes. While these changes are taking place, the nuclear membrane disappears and 24 chromosomes can be seen lying in one plane in the centre of the cell (see text-fig.). Fine



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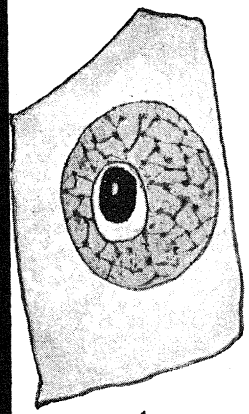

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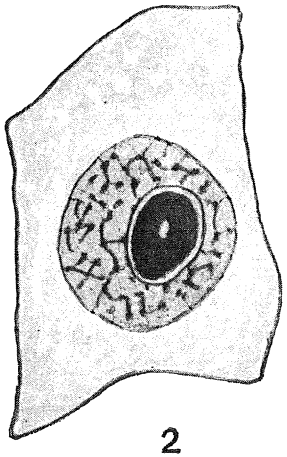

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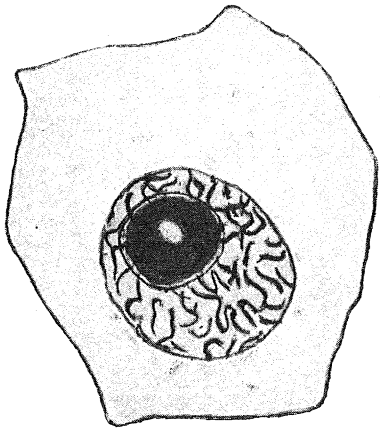

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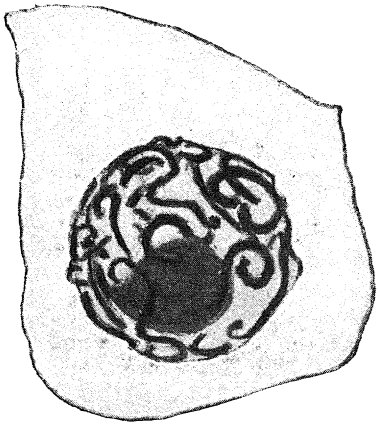

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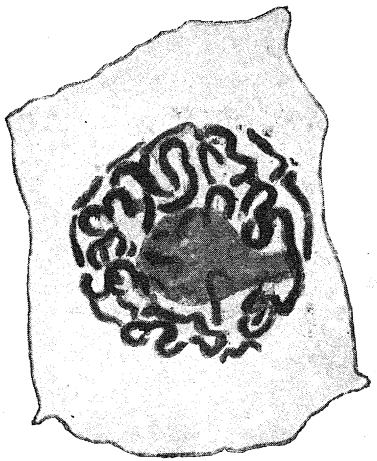

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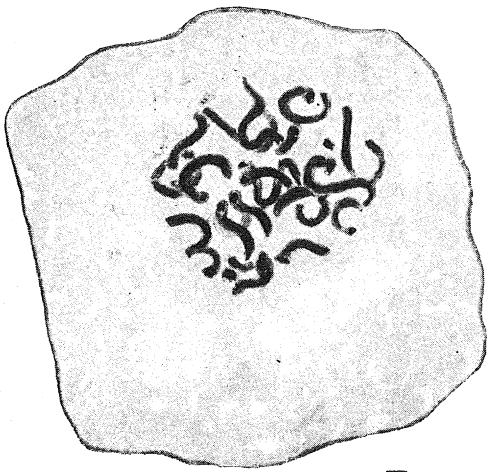

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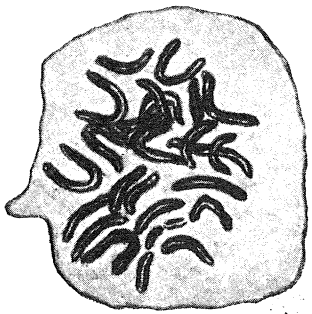

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fibrils appear in the cytoplasm to form the spindle, but they are not focussed at the spindle poles ; they travel more or less parallel to each other from the equator of the spindle and converge only slightly towards its poles. The chromosomes undergo their final divisions at the equator of the spindle, the daughter chromosomes then separate and proceed in opposite directions along the spindle, till they reach nearly to its ends. The two groups of daughter chromosomes now reorganise themselves into two daughter nuclei. While this process is in progress a cell plate begins to appear at the equator of the spindle. At either end of the cell plate there are conical structures with which the cell plate is continually extended at its margins, until it cuts completely through the cells and the division is complete.

Prophases.

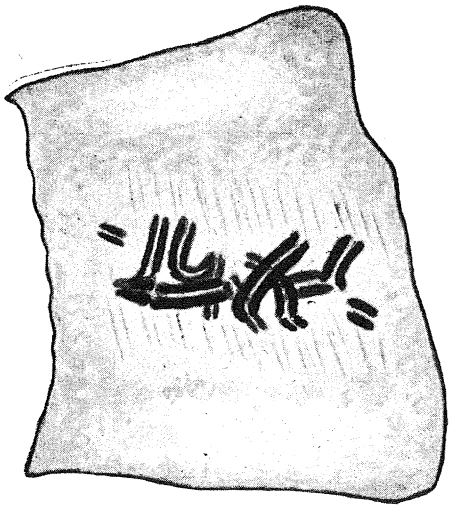
The early prophases consist in a gradual transformation of the nuclear framework into a discontinuous thread called the spireme. This involves the following changes :—The nucleus enlarges in size and the staining reaction of the chromatin granules increases remarkably and they come closer to each other. The reticulum or the linin network also becomes conspicuous and takes up a brilliant stain, Plate XXXIII, Fig. 2. This breaks up at various places and gives rise to numerous delicate convolute threads with chromatin granules studded over them like beads. The number of these threads is variable and has been counted from 36 to 48 in various cells, Plate XXXIII, Fig. 3. These threads join together, grow thicker and take up a darker stain, Plate XXXIII, Fig. 4. They are often seen in direct contact with the nuclear membrane which gets used up in their make-up. By the joining together of these threads a discontinuous spireme is formed and it lies in the form of irregular loops. As these changes are taking place in the reticulum there are at the same time remarkable changes going on in the nucleolus. Wager [1904] describing the changes in the nucleolus during the prophases mentions that as the nucleolus decreases in size the nuclear thread becomes more and more prominent and stains in similar way as the nuc,eolus. Cavara [1898] as the result of his researches on the nucleoli of various plant cells states that during prophases of divisions the nucleoli decrease somewhat in volume and break up, and at the same time the linin thread contracts and breaks up into chromosomes. Farmer's [1895] observations on Liverworts support the view that nucleolar substance decreases with the growth of chromosomes. According to Wilson [1928], true nucleoli often persist with only slight change while the spireme forms, and in later stages rapidly diminish in size, fragment and disappear. The author when going through the illustrations of (1) Digby [1910] in her studies on the somatic divisions of Galtonia (Fig. 1-10), (2) Fraser and Snell [1911]

in their paper on the vegetative divisions in *Vicia faba* (Fig. 10-14), (3) Davis [1911] in his cytological studies on Oenothera (Fig. 21-27) and reduction division in *O. Gigas* (Fig. 50-57), (4) Latter [1926] in her paper on pollen development of *Lathyrus odoratus* (Fig. 3-7) and Fig. (22-26), noticed that the nucleolus gradually increases in size as the prophases advance and the nuclear thread becomes more and more prominent, although this fact has not been mentioned by them. The increase in size of the nucleolus during the process of division has been reported by Mitzkewitsch [1898] in his studies on Spirogyra. He states that in the process of division as the prophases advance the nucleolus increases in size, its membrane disappears and it becomes irregular in form.

An examination of the prophase stages in *Capsicum annuum* revealed a similar change in the size of the nucleolus. It was seen that the nucleolus which is spherical in form and dark staining in the resting nucleus, gradually enlarges in size, gets only faintly stained with haematoxylin and becomes pale. Its form changes from spherical to oval and later on becomes irregular (Plate XXXIII, Figs. 1 to 6). As these changes are taking place the clear space surrounding the nucleolus also slowly disappears. It appears probable that through a protuberance from the nucleolus (Plate XXXIII, Figs. 5 to 6) some material like nucleic acid due to the presence of which it takes up a dark stain during the resting stage flows to the reticulum during mitotic transformation, resulting in the faint staining reaction of the nucleolus and dark staining reaction of the reticulum. Berghes [1919] in somatic nuclei of Marselia showed that the bulk of basichromatin material of the nucleus is lodged in the nucleolus and is transferred to the reticulum in prophases. Flemmings [1882] held that the nucleolus contributes material to the formation of chromosomes. Definite proof for this has been advanced by the studies of Wager [1904], Cardiff [1906], Nichols [1908], Cleland [1922], Vancamp [1924], Latter [1926], Sethi [1930] and the present writer. The very fact that at the time when the chromosomes and the nuclear framework have become completely oxyphilic the nucleoli are often intensely basophilic and *vice versâ* suggests that the nucleoli are the storehouses of some material like nucleic acid which is drawn upon at the prophase when the chromosomes are resuming their basophilic character and helps in their formation.

The most interesting point which I have observed and which strengthens the above conclusion is the development of a small protuberance of the nucleolus during prophase which joins the reticulum.

Now the natural consequence of the flow of basichromatic material of the nucleolus into the chromosomes should be a decrease in the size of the nucleolus. But this does not happen, the nucleolus instead of decreasing increases in size (Plate XXXIII, Figs. 1-6). Nothing definite can be said as to why this increase takes place. The gradual disappearance of the clear space surrounding the nucleolus sug-



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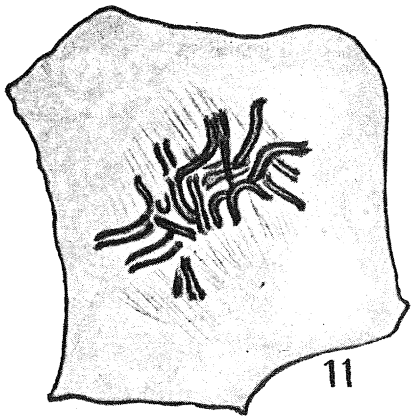

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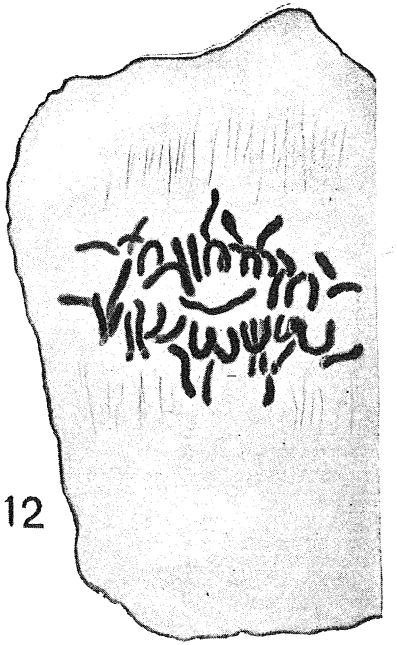
10a 10b 10c



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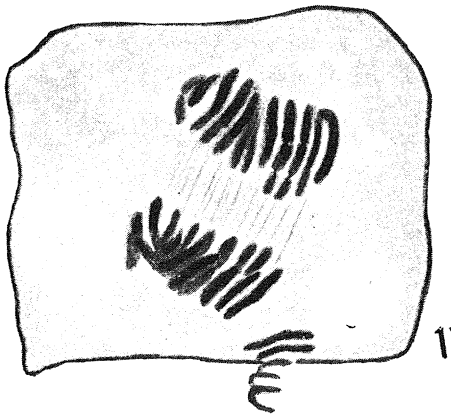

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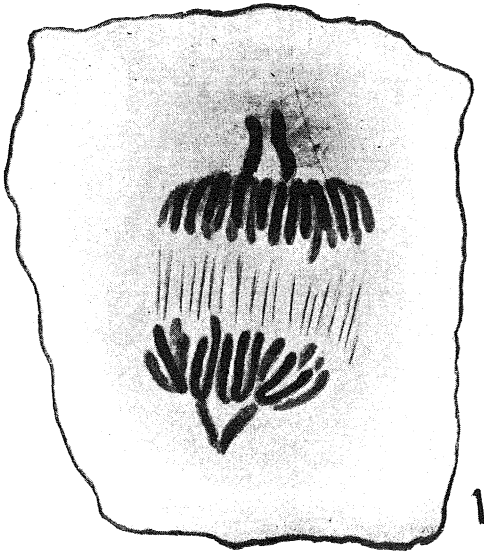

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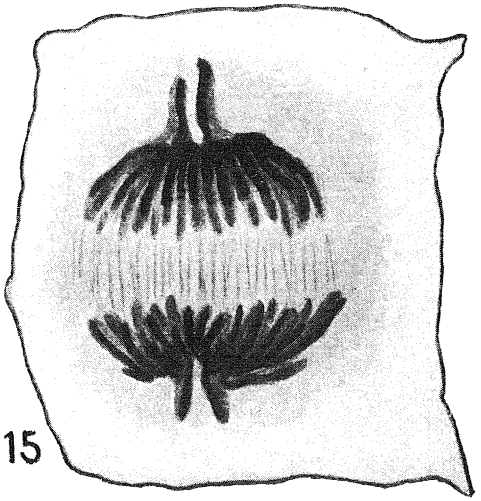

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gests that probably the fluid contained in this clear space enters the nucleolus and causes increase in its size. The nuclear membrane disappears during late prophases, but the nucleolus still persists. It is irregular in outline, pale in colour and attains its largest size at this stage. The spireme thread which is single to begin with now segments and the double nature of its segments is often clear. These segments assume the form of chromosomes and can easily be counted as twenty-four in number lying in a single plane at the centre of the cell in a transverse section (Plate XXXIII, Fig. 8). All the chromosomes are not of the same size and shape.

As these changes are taking place the nucleolus disappears, and the spindle fibres begin to make their appearance. Strasburger [1888] who observed the disappearance of the nucleolus at about the time the spindle fibres appear during prophases of mitosis concluded that nucleolus is a mass of reserve kinoplasm which gives rise indirectly to the achromatic figure. It appears that perhaps the fluid which flows from the clear space into the nucleolus coagulates when the nucleolar membrane bursts and gives rise to the spindle fibres. The idea that the author could form about the behaviour of the nucleolus in *Capsicum annuum* can be summarised as follows :—

The nucleolus is the storehouse of chromatic material which during prophases flows into the spireme, thus showing that it is intimately connected with the formation of chromosomes. While the chromatic material is flowing out from the nucleolus, the clear fluid from the cavity surrounding it is coming into the nucleolus and causing increase in its size. As prophase advances and the nucleolar membrane bursts this fluid flows out and by its coagulation gives rise to the spindle fibres.

Metaphase.

As the chromosomes lie nearly in a single plane in the centre of the cell at the final prophase, the longitudinal split is obscure due to close apposition of longitudinal halves. But soon after the spindle fibres make their appearance and become attached to the chromosomes, the split is clear and the chromosomes are plainly double (Plate XXXIV, Fig. 9). The mode of attachment is not the same in all chromosomes. The short chromosomes and the rod-shaped chromosomes show terminal or sub-terminal attachment, while V or U-shaped ones are attached at their apexes (Plate XXXIV, Figs. 10a, 10b and 10c). The chromosomes are not arranged on the periphery of the spindle, but they lie actually inside the spindle. The longer ones, of course, are towards outside (Plate XXXIV, Fig. 11). Two pairs of chromosomes possess satellites (Plate XXXIV, Figs. 9 and 13).

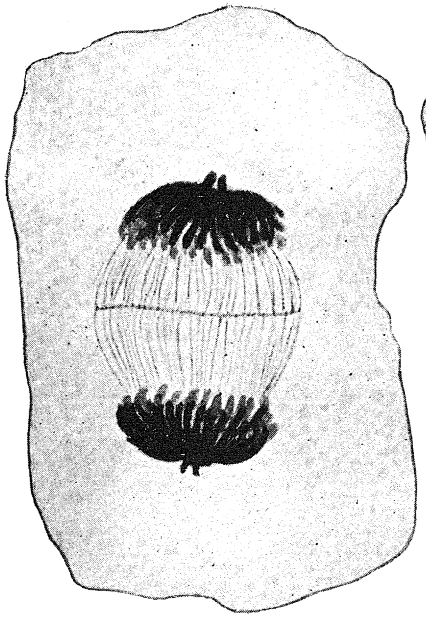
Anaphase.

In the beginning of the anaphase the daughter chromosomes (the halves of the double chromosomes) draw apart from each other. The shorter chromosomes get separated sooner and reach the poles earlier (Plate XXXIV, Figs. 9 and 11). A number of stages could be observed in various slides examined showing the movement of the chromosomes from the equator towards the poles of the spindle (Figs. 11, 12 and 13). On reaching the poles the chromosomes lie like superposed rays of an umbrella one whorl above the other (Plate XXXIV, Fig. 15). There appears to be a whorl of smaller chromosomes inside the outer whorl of longer ones. Anaphase is considered to be a stage which is passed off rapidly on the grounds that a very few stages of this are seen—if that be the criterion—the anaphase appears to pass rather slowly in this case. The satellites of the chromosomes are very clear in this stage (Plate XXXIV, Fig. 13).

Telophases.

At the beginning of the telophase the daughter chromosomes remain closely pressed together for some time at the ends of the spindle (Plate XXXV, Fig. 16). They draw in their free ends and form a compact knot (Plate XXXV, Fig. 17), (as in Galtonia 7b). Later on this aggregation loosens and the outline of the daughter chromosomes again becomes visible, but they are now attached laterally to their neighbours at various points in the middle (Plate XXXV, Fig. 18). As the telophase advances the free extremities of the daughter chromosomes become less and less deeply stained, numerous fine connections appear between them and ultimately in the phrase of Greoire "a network of networks" is formed. The chromatin granules get separated from each other and are evenly distributed over the network. These changes do not take place simultaneously in all the nuclei for in some daughter nuclei pieces of homogeneous-looking chromosomes may still be present, while the outline of others is lost.

The formation of the nuclear membrane has been a subject of much controversy. Lawson [1903] has interpreted it as merely a denser limiting layer of cytoplasm. Strasburger [1888] has also expressed similar views—he regards it as analogous to the outer cell-membrane and designates it accordingly as inner cell-membrane. Some have gone so far as to deny the very existence of a nuclear membrane as a definite structure, regarding it as only an optical allusion due to the meeting of cytoplasm and nucleoplasm. The studies of the Mitotic divisions in *Capsicum annuum* clearly show that nuclear membrane is a definite structure belonging to the nucleus. The nuclear membrane approaches the nuclear framework in its staining reaction more than anything else. It is



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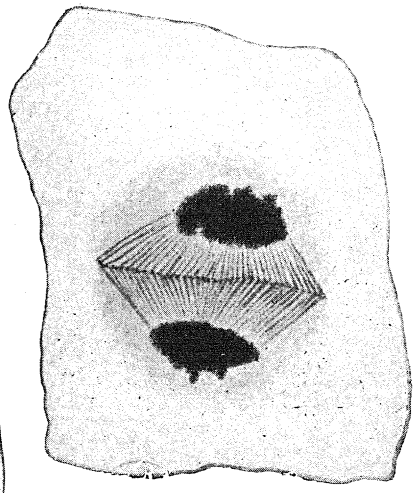

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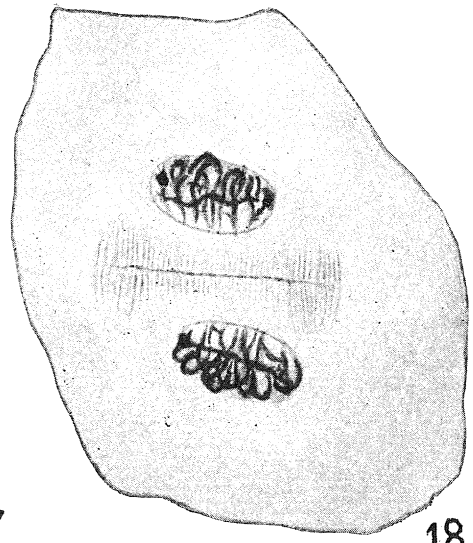

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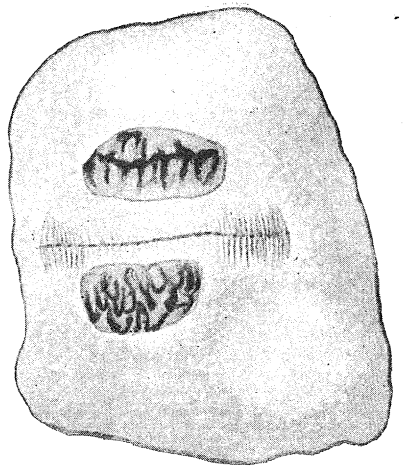

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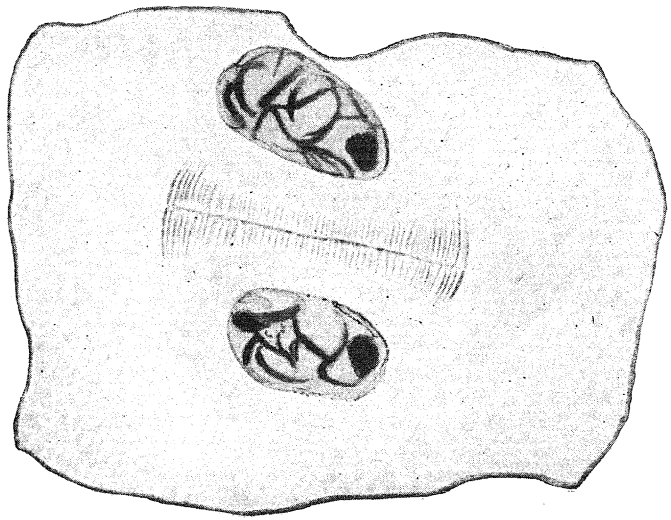

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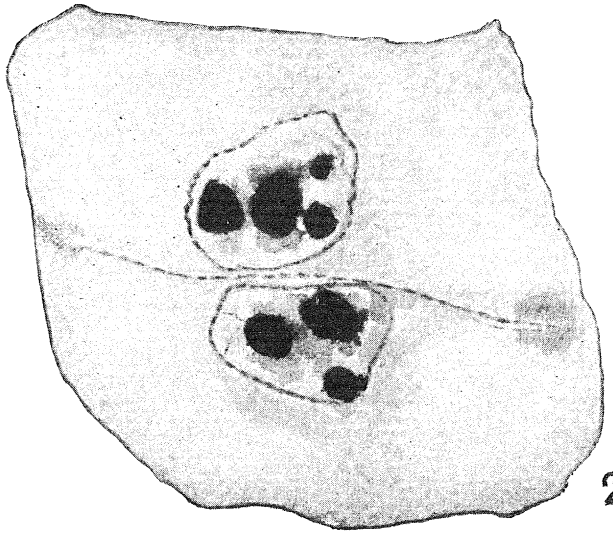

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studded over with chromatin granules as is the internal network and appears distinctly to be formed from the periphery of the outer chromosomes. The studies of Kite and Chambers support this view and it is in accordance with the results of the more recent investigations.

When these changes are taking place one or two and sometimes even more dark staining bodies are formed (Plate XXXV, Figs. 20 and 21) evidently by the flowing together of the substance of the chromosomes. They are irregular in outline to begin with, but later on they assume definite form and give rise to the nucleoli. The nucleoli are organised long after the nuclear membrane has been formed around the nucleus.

Now coming to the Achromatic-Figure. At the beginning of the telophase the fibres of spindle run parallel to each other (Plate XXXV, Fig. 15) but as the telophase advances the fibres bend outwards at the middle and form a barrel-shaped phragmoplast (Plate XXXV, Fig. 16). It next widens and its shape changes from that of a barrel to that of a biconvex lens (Plate XXXV, Fig. 17).

The position of the daughter nuclei (still unorganised) changes with the change in curvature of the fibres. They follow the apparently shortening fibres towards the equator of the spindle and come to lie quite close to the newly forming cell plate (Plate XXXV, Figs. 16 to 21). They remain in this position until cell division is complete and the cell plate has split to form the two cell membranes and a separating wall formed between them. The daughter nuclei then begin to travel back and come to lie in the centre of the daughter cell—which is now independent and a self-contained unit.

Signs of the cell plate formation begin to appear long before the nuclear membrane appears around the daughter nuclei. Treub [1887] points out that cell plate formation is a progressive process and that the cell plate widens gradually. It has been seen in *Capsicum* that soon after the anaphase has passed the spindle fibres begin to thicken in the equatorial region, the thickenings increase and a cell plate is formed. In a longitudinal section of the spindle the cell plate appears to be composed of dark staining particles (edge view of the cell plate) (Plate XXXV, Figs. 16 to 21). It appears probable that the material in the spindle fibres flows from the poles towards the equator, *i.e.*, material from the extremities of each fibre comes to its middle point and the enlarged middle points of the adjacent spindle fibres fuse with one another and result in the formation of the cell plate. The fact that the fibres go on becoming shorter and shorter from the poles towards the equator, and that the stain is less towards the extremities of the fibres than their middle supports this view.

At each end of the cell plate more or less at right angles to it, appears a somewhat conical mass of fibres as seen in the longitudinal section of the spindle

(Plate XXXV, Figs. 18, 19). Sometimes the cell plate reaches one side of the cell earlier than the other in which case the conical mass of fibres is seen only on one end of the cell plate. This is the ring of Kinoplasmic fibrilliar material appearing continually in a centrifugal direction on the outside of the cell plate which goes on adding to the cell plate till it completely cuts across the cell. The fibres of this ring just like the fibres of the spindle thicken, shorten and finally fuse to produce the cell plate material. Bailey [1920] describes and figures such cell division stage in cambium initials, which are several hundred times as long as they are wide and divide longitudinally by an extraordinary extension of the cell plate. Goldstein [1925] makes mention of a similar rim of fibrilliar kinoplasm which appears as a hollow about the portion of the cell plate already formed and continues growing till it reaches the wall of the cell, in vacuolated cells of tobacco stem tip and very young leaves.

(3) Haploid Number.

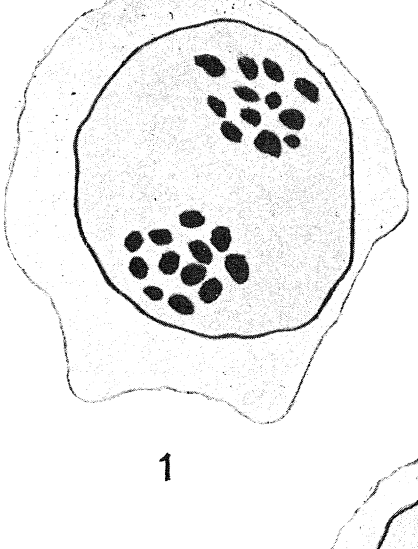
A Modification of Smear Method.

Some buds of *Capsicum annuum* types and also of some of the hybrids were fixed last winter in Cornoy's fluid, Shaffner's weak solution and Allen's modifications of Bouin's fluid, but no division stages could be fixed, where counts could be made. Perhaps the fixatives do not penetrate so rapidly through the floral appendages as to ensure the fixation of such stages. In order to ascertain the haploid number in this species this year the Smear Method as described by Taylor [1929] was resorted to. The fixing fluid first used was a chromo-osmic-acetic mixture of the following constitution :—

10 per cent. acetic acid	2 c.c.
10″ chromic acid	2 c.c.
Osmic acid dissolved to 2 per cent. strength in 2 per cent. chromic acid . . .	1·5 c c.
Distilled water	8·2 c.c.
A few crystals of maltose.	

But this fixative caused too much blackening which could not be bleached by Hydrogen peroxide. Allen's modification of Bouin's fluid was tried next and found quite suitable. Taylor [1929] recommends the use of slides cleaned by a long stay in battery fluid to ensure fixation, but the writer found that the ordinary white slides served the purpose equally well. A preliminary examination of the young buds was made to find out the time at which the divisions take place. About 10 A.M. was found to be the right time when the divisions were quite abundant. A few anthers were excised from the bud by removing the calyx and

PLATE XXXVI.



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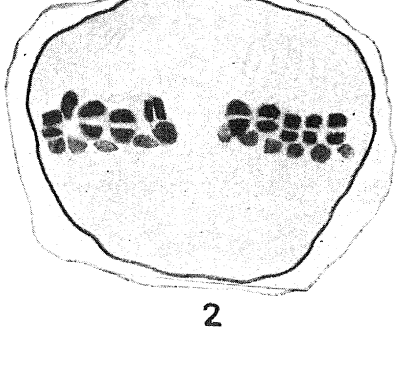

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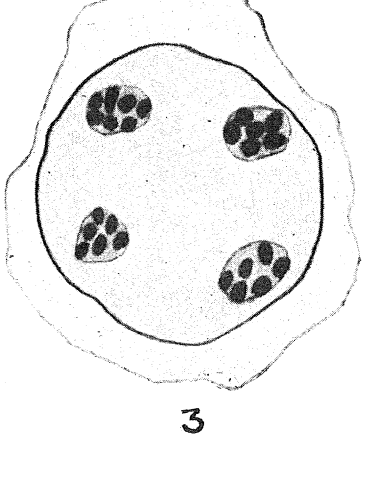

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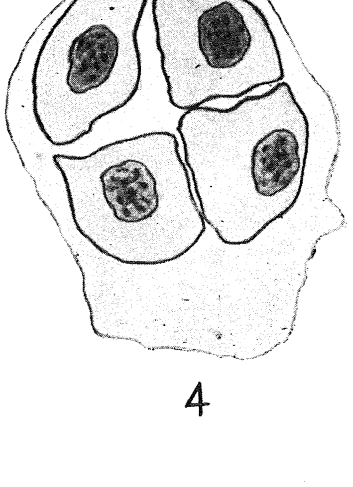

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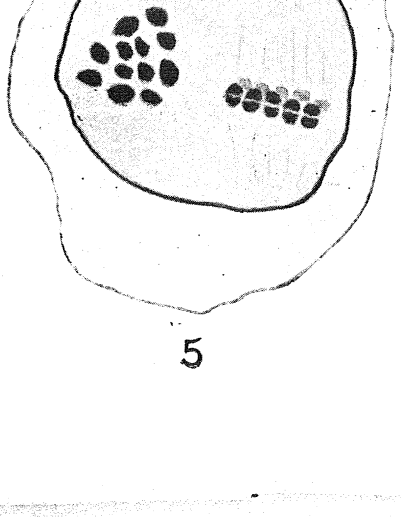

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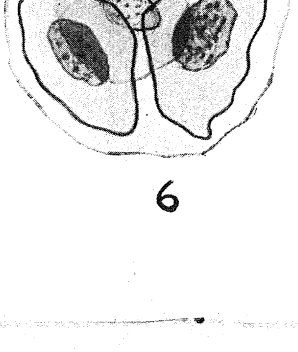

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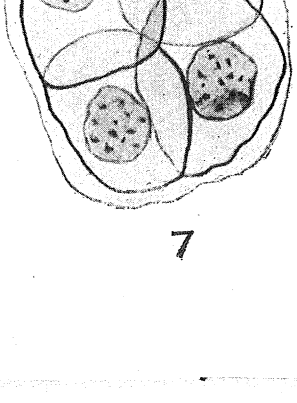

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corolla and immediately crushed and spread over on the slide with a single smart and swift stroke of a clean scalpel so as to obtain a thin uniform smear. Taylor recommends that after this the slides must be immediately inverted on the fixing fluid bringing it down in a horizontal position, so that the whole smeared face is wet simultaneously, for if the slide is brought down on the fluid in an oblique position much of the material will wash off. To secure this the slide is placed with smeared face downwards on a glass rod in a petri-dish containing the fixative and allowed to remain in this condition for a few minutes and then turned right side up and left for the full time of fixing. The author found this method rather inconvenient, only one or two slides could be placed in one petri-dish, thus necessitating the carrying of a number of petri-dishes full of fixing fluid to and fro from the field and a lot of fixing fluid was used up. Therefore the petri-dish was replaced by a staining dish with 12 grooves, which could accommodate about a dozen slides at a time and only hundred cubic centimeters of fixing fluid were required to fill it. One slide after another as it was prepared was placed immediately in a vertical position in the staining dish containing the fixing fluid. The fixing fluid (Allen's modifications of Bouins Fluid) was allowed to act for an hour or so and then poured back for use at another occasion. It is generally recommended that after using fixative containing Picric acid washing should be done with 70 per cent. Alcohol. But it was found that it caused too much shrinkage, so washing was done in changes of 30 per cent. Alcohol followed by grades of 20 per cent., 15 per cent., 10 per cent. and 5 per cent. Alcohol. A few drops of saturated solution of lithium carbonate were added now and then. In this way the slides were brought down to water and washed in running water for an hour. The slides were stained according to Kaufmann's [1927] modification of the Taylor's staining schedule and gave quite good results.

(1) Mordanting in 2 per cent. iron alum solution for 45 minutes to an hour.

(2) Washing in running water for about 10 minutes.

(3) Staining for an hour or so in $\frac{1}{2}$ per cent. haematoxylin solution.

(4) Differentiating in 1 per cent. solution of iron alum.

The slides were dehydrated in grades of Alcohol, cleared in Xylol and mounted in balsam.

This modification of haematoxylin-balsam-smear method has been described in detail so that it may be of use to other workers carrying on similar research.

Chromosome Counts.

An examination of the smear preparations showed that the reduced number of chromosomes appears at the first mitosis in the pollen mother cell (Plate XXXVI, Fig. 1). The two nuclear divisions of meiosis occur in rapid succession

before any wall formation begins and four microspore nuclei are formed inside the microspore mother cell. Each microspore nucleus becomes invested by a delicate wall which is independent of the wall of the mother cell and thus four microspores are formed. The arrangement of microspores in the mother cell is commonly tetrahedral (Plate XXXVI, Figs. 6 and 7) resulting from simultaneous mode of division of its nucleus, but cases are met with where the arrangement is bilateral (Plate XXXVI, Figs. 3 and 4) due to successive divisions taking place during meiosis.

There appears to be a tendency for the bivalents to come close to each other at the poles after each division and thus give an impression that the haploid number of chromosomes is six (Plate XXXVI, Fig. 3). Such-like stages must have led Kostoff [1926] to the erroneous conclusion that the haploid number is six. But counts were made in many dividing microspore mother cells at the first as well as the second division and it was found that there were twelve chromosomes (see microphotograph, Plate XXXVII). This confirms the result obtained from the study of somatic divisions in the root-tips, where the chromosomes were counted to be twentyfour in number. Thus the haploid number of chromosome is 12 and diploid 24 in *Capsicum annuum*

Summary.

1. The diploid number of chromosomes in *capsicum annuum* is 24.

2. The nucleolus during the prophases of mitosis gradually increases in size. It gives only a slight reaction for chromatin when the linin network becomes prominent and takes up a dark stain.

3. The nucleolus is intimately concerned in the formation of chromosome, it puts forth a small protuberance which joins the spireme and through this protuberance the chromatic material stored in the nucleolus is possibly transferred to the chromosomes.

4. The nuclear membrane appears to be formed from the periphery of the outer chromosomes and is used up when they are being formed.

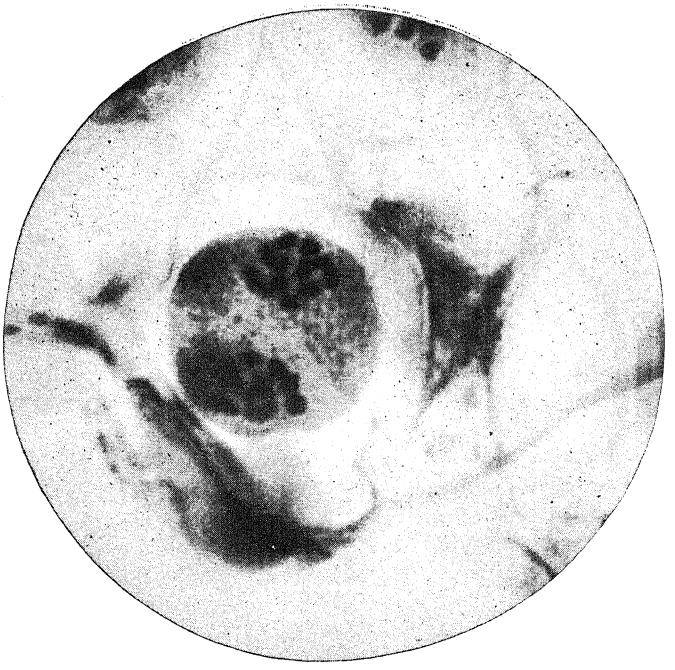
5. The cell plate is continually extended at its free margins by means of the Kinoplasmic ring until it finally cuts completely across the cell.

6. A modification of Haematoxylin-balsam-smear method as used for the study of chromosome numbers in pollen grains is described in detail in the text.

7. The haploid number of chromosomes is twelve as reported by Huskins and Lacour [1930] and not six as mentioned by Kostoff [1926].

8. Simultaneous and successive divisions take place in the different microspore mother cell giving rise to tetrahedral arrangements of microspores in some and bilateral in others, although the former is more common.

PLATE XXXVII.



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Explanation of Plates.

Figures 1-21 in plates XXXIII, XXXIV, and XXXV, showing the different stages of mitotic division are based on preparations of material fixed in Allen's modification of Bouin's fluid and stained in iron-haematoxylin and have been drawn with the aid of a Leitz Camera Lucida. A Zeiss 1-12 inch homogene immersion objective has been used with K 12 Zeiss ocular—thus giving a magnification of 1500. All the drawings have been made at the level of the base of the microscope and not at the level of the stage ; so the magnification of the drawings is proportionately greater.

Figures 1-7 in plate XXXVI showing the dividing pollen-mother cells are based on smear preparations only and have been drawn as mentioned above.

Plate XXXVII is an enlarged microphotograph of a pollen-mother cell.

Plate XXXVIII. Prophase stages as seen in cells in the transverse sections of the root tip.

Figure 1. A cell with a dark staining vacuolar nucleolus and a faint reticulum. Note the clear space surrounding the nucleolus.

Figure 2. Less dark stained nucleolus but larger in size and a prominent reticulum.

Figure 3. Still larger nucleolus and network broken into small thread like structures.

Figure 4. Enlarged nucleolus with a protuberance and the discontinuous spireme.

Figure 5. Portions of spireme in direct contact with nuclear membrane, nucleolus still bigger.

Figure 6. Nucleolus very large in size, irregular and pale, nuclear membrane disappearing.

Figure 7. Nucleolus disappears. Spireme breaks up, nuclear membrane absent.

Figure 8. 24 chromosomes in the centre of the cell—the equatorial plate. Note the cleft in the chromosomes.

Plate XXXIV. Metaphase and Anaphase stages as seen in cells in the longitudinal sections of the root tip.

Figure 9. Metaphase—chromosomes just separating. Note two pairs of chromosomes with satellites.

Figure 10a, 10b, 10c. Different modes of attachment of the fibres.

Figure 11. Anaphase. Chromosomes have separated from each other.

Figure 12. Anaphase.

Figure 13. Anaphase—note the satellites ; two pairs of chromosomes have broken out.

Figure 14. Anaphase. Chromosomes have reached the poles of the spindle.

Figure 15. Final Anaphase. Note the superposed nature of chromosomes.

Plate XXXV. Telophases.

Figure 16. Daughter chromosomes closely pressed at the ends of the spindle. Thickened fibres at the equator indicating the beginning of the cell plate formation.

Figure 17. Aggregation of chromosomes into knots at the poles of the spindle.

Figure 18. Laterally connected chromosomes—ring of kinoplasmic fibres cut longitudinally.

Figure 19. Daughter nuclei in reconstruction—cell plate extending.

Figure 20. 2000 X. Note nuclear membrane formed from the periphery of outer chromosomes. Nucleolar bodies are appearing.

Figure 21. Note the position of the daughter nuclei—the cell plate has nearly reached the walls of the cell.

Plate XXXVI. Stages of Mitotic Division.

Figure 1. Twelve chromosomes on either pole of the pollen mother cell after the first reduction division.

Figure 2. Second division metaphase. Note the simultaneous mode of division.

Figure 3. Second division very early telophase, the chromosomes have come close together and appear as if they are six.

Figure 4. Bilaterally arranged microspores within the wall of the mother cell.

Figure 5. Successive mode of division. One set of chromosomes in second division metaphase.

Figures 6 and 7. Tetrahedrally arranged microspores within the wall of the mother cell.

Plate XXXVII. An enlarged microphotograph showing twelve chromosomes on either pole of the pollen mother cell after first reduction division.

THE INHERITANCE OF CHARACTERS IN RAGI, *ELEUSINE CORACANA* (GÆRTN), PART I.

PURPLE PIGMENTATION.*

BY

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(With Plates XXXVIII to XLI.)

INTRODUCTION.

Elcusine coracana (Gærtn), *ragi* of Madras, *nagli* and *marua* of North India, is a millet grown over an area a little under 4 million acres in British India and another $2\frac{2}{3}$ millions in Indian States (*vide* statistics below).

Agricultural Statistics of India, 1927-1928, area under ragi.

Provinces (British).	*Area in acres.*
Madras and Coorg	2,304,893
Bihar and Orissa	712,900
Bombay	627,362
United Provinces	163,848
Punjab	21,836
Central Provinces and Berar	12,372
Bengal	8,200
Ajmer-Merwara and Manpur Pargana	298
	3,851,709
Indian States.	
Mysore State	2,334,176
Hyderabad State	272,795
Madras States	30,710
Punjab Agency States	14,422

* A paper read at the Fourteenth Annual Meeting of the Indian Science Congress at Lahore (1927), and supplemented with further data.

Indian States—contd.	
Punjab States	12,528
Kashmir State	2,353
United Provinces States	2,157
Rajputana States	1,047
Bombay States	709
Central India States	584
	2 671,481

In British India, the Madras Presidency grows about $\frac{2}{3}$ of the area, Bihar and Orissa about $\frac{1}{5}$ and Bombay about $\frac{1}{6}$. In Indian States $2\frac{1}{3}$ out of $2\frac{2}{3}$ millions is to the credit of Mysore, a State adjacent to the Madras Presidency. This cereal is therefore one in which Madras has a preponderant interest. The study of this millet was begun in the year 1924 and this paper records one aspect of the progressed work, namely, purple pigmentation in the plant—the various types, their inter-relationships and inheritance, and the behaviour of these pigmented types towards the unpigmented green-throughouts.

Description.

Eleusine coracana (Gærtn) is a small-grained cereal belonging to the group of cultivated crops called millets. A medium-sized annual, it grows to a height of 3 to 4 feet with a capacity to tiller and branch freely. An individual plant tends to look in general outline and configuration a chandelier. The stems are somewhat compressed, elliptic, tough and smooth and much ensheathed, exposing very little of the internodes. The base of the leaf-sheath develops a belt of swollen tissue which will hereafter be referred to as the *nodal-band*. The sheath and the leaf-blade join together and form a special light-coloured triangular piece of tissue to be hereafter referred to as the *junction*. The leaf-blade has a prominent midrib, and in spite of this many of the well grown leaves show a tendency to snap and hang down about their upper middle. Such leaves will hereafter be designated *bent-leaves*. These bent-leaves gradually cease to function and dry off. The inflorescence which is characteristic of this cereal is borne on a long peduncle, from the end of which 4 to 6 spikes radiate in a whorl. The end of the peduncle from which these radiate is referred to as the *basal-ring*, owing to the presence of an irregular ring of slightly swollen tissue. The spikes are called *fingers*, and the odd one, often found attached to one edge of the flattened peduncle a little lower than the basal ring, is called the *thumb*. The spikes are either straight or curved inwards. In each finger there are a number of spikelets (60 to 80) which are arranged in two rows and alternately attached to one side of a flattened rachis. The spikelets are sessile and contain 5 to 8 glumes each, of which the two lowermost are barren and the rest are paleate

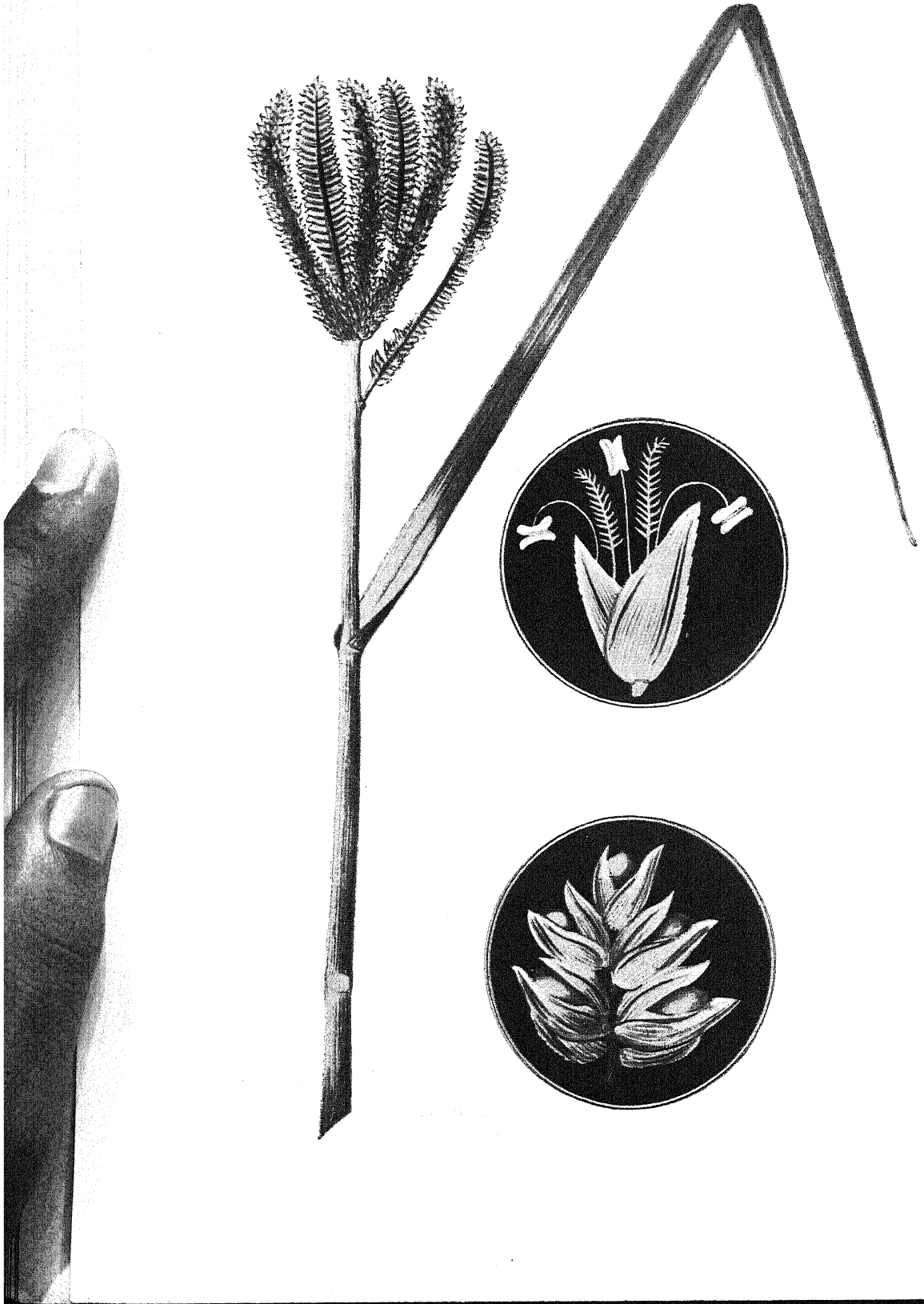
enclosing a complete flower consisting of an ovary with two feathery stigmas and three anthers. The anther sacs, during dehiscence, split longitudinally and with their inverted margins present the appearance of two boats back to back. The ovule develops into a seed which is globular and encased in a membraneous pericarp.

Purple Pigmentation.

As in the case of all cereals, *ragi* falls into the two broad groups of purple pigmented plants and non-purple pigmented plants which are hereafter designated *Green-throughouts*. The purple pigment is of the anthocyanin type. The presence of purple pigmentation and the details of its distribution in the plant serve as a guide to the broad groupings of the varieties of the crops, in each of which other accessory factors like panicle shape, etc., afford subsidiary groups. The build of the *ragi* plant makes it a rather difficult meterial in which to pursue purple pigmentation with that clarity which marks its presence in rice and Italian millet. This difficulty notwithstanding, attempts have been made to study and classify the various pigmented types of *ragi*. It is this purple pigmentation, mostly of the earhead, that gives a field of *ragi* its characteristic violetish appearance when in full bloom.

Development of Purple Pigmentation.

In the commonest type of purple-pigmented *ragi*, the first indication of the presence of this purple pigmentation is found at the junction in seedlings as young as 10 days old. With the growth of the seedling and the consequent growth in the leaf-blade, bent-leaves begin to appear and in these, at the bend and on to the tip, there is a run of purple. At a further stage of growth when the first nodes show out, their nodal-bands take on the pigmentation, manifested here with a darkish tint. With increased growth, such bits of internode as the intense ensheathing lets out, begin to take on a wash of purple, more of a self-colour and less of lines. When the plant starts flowering and the panicle comes out, the emerging glumes and paleæ develop the colour prominently at the tips and in their nerves. When the head is fully out, the basal-ring shows the colour markedly. The most striking manifestation is in the stigmatic feathers and the anthers freshly emerged and a mass of these, together with the coloured glume tips, give a field of purple-pigmented *ragi*, the violet look peculiar to this field crop. As flowering proceeds the peduncle gets coloured up also. The optimum manifestation of purple pigmentation is from the flowering to the milky stage of the grain, after which there is a gradual falling off in the depth of the pigmentation in the earhead. Advancing age, however, loosens out the internodes, which together with the prominent nodal-bands retain the purple pigmentation as long as they continue to be sappy.



Light naturally plays a very important part in the manifestation of this purple pigmentation, the best colour being in parts exposed to direct sun-light. The eastern sides of the plant get more deeply tinged than the western. The pigment is of the anthocyanin type and is confined to the outer epidermel cells. In sections of pigmented material like the sheath base and internode, etc., it shows mostly as a bluish granular deposit with some cells showing pinkish-coloured cell sap. It rarely extends to the sub-epidermal layers.

PURPLE-PIGMENTED TYPES.

There are three broad groups of purple-pigmented plants.

Group I. Purple (Plate XXXVIII).
„ II. " Dilute " Purple (Plate XXXIX).
„ III. " Localised " Purple (Plate XL).

Group I. The Purple.—The pigmentation in this group, is prominently manifested in the junction, bent-leaf, nodal band, internode, peduncle, basal-ring, glume, anther and stigma. This is the commonest kind under cultivation.

Group II. The " Dilute " purple.—This type is a definite variant of Group I, showing a quantitatively less amount of pigment. It is similar to the purple in junction, bent-leaf, internode, peduncle, bassal-ring, anther and stigma, but differs from it in showing a marked reduction of pigment in the glume and nearly a total absence in the nodal-band which is almost green excepting in rare cases where a few odd specks of purple appear.

Group III. The " Localised " Purple.—This type shows the least amount of purple, which is confined to the floral parts. The glumes show a very little amount of purple which can be detected only by a hand lens. The anthers after dehiscence show a faint ring of purple on the margins of the anther slits and the stigma is so little tinged with purple as mostly to escape detection by the naked eye. In spite of this faintness of manifestation, the little pigmentation there is, is just enough to dullen down the freshness of the green background, so that in mass effect, these localised purples are separable from the green-throughouts. (Plate XLI).

In addition to these three definite groups of pigmented types, there are some sub-groups under each group varying in the direction of increasing or decreasing depths of pigmentation of all or some of the parts. As already mentioned, *ragi* is such a difficult material for the pursuit of this study and as such, attention has been confined to the above three patent groups and their genetic inter-relationships. These other variations of the major types are however under further intensive study.

Genetic relationships.

Purple pigmentation in *ragi*, as is generally the case in other crops, is dominant to the unpigmented condition. The localised purple is the basic purple and will be designated by the symbol PP, while the green-throughout that altogether lacks purple pigmentation by the corresponding pp. The purple pigmentation factor is supplemented by the action of two intensifying factors I_1 and I_2. I_1 acts on basic purple, intensifying and bringing it up to the "Dilute" purple class. This class is represented by the symbol $PPI_1 I_1$. I_2, the second intensifying factor, acts only in the presence of I_1. With "Dilute" purple it produces full pigment in glumes and nodal-bands and raises it to the purple class symbolised P P I_1 I_1 I_2 I_2. I_2 by itself, however, in the absence of I_1 fails to have any visible effect on the "Localised" purple, beyond making it consist of two genetic groups, *viz.*, PPi_1 i_1 I_2 I_2 which is allelomorphic to the purple and PPi_1 i_1 i_2 i_2 which is allelomorphic to the "Dilute" purple.

Corresponding to the four purple-pigmented genetic groups, there are four groups of green-throughouts which are their genetic recessive analogues, *viz.*, ppI_1 I_1 I_2 I_2, ppI_1 I_1 i_2 i_2, ppi_1 i_1 I_2 I_2 and ppi_1 i_1 i_2 i_2. They look alike and by suitable breeding tests, their latent genetic capacities to respond to the P factor are made manifest.

Abbreviations used.

E. C.	for *Eleusine coracana*.
G. T.	for Green-throughout.
L. P.	for Localised Purple.
Dil. P.	for Dilute Purple.
P.	for Purple.

Artificial crosses are given Roman numbers. The year under them is the year when the cross was made. Under natural crosses the year indicates the spotting of the hybrid.

Key to the scheme of crosses presented in the tables.

Table No.	Behaviour
1	(L.P.—G.T.) Segregation for P factor only. 3 : 1
2	(P.—G.T.) Segregation for P—Homozygous for I_1 and I_2. 3 : 1
3	(P.—L.P.—G.T.) Segregation for P and I_1—Homozygous for I_2. 9 : 3 : 4
4	(P.—Dil. P.—G.T.) Segregation for P and I_2—Homozygous for I_1. 9 : 3 : 4
5	(P.—L.P.) Segregation for I_1—Homozygous for P and I_2. 3 : 1
6	(P.—Dil. P.) Segregation for I_2—Homozygous for P and I_1. 3 : 1
7	(P.—Dil. P.—L.P.) Segregation for I_1 and I_2—Homozygous for P. 9 : 3 : 4
8	(P.—Dil. P.—L.P.—G.T.) Segregation for all the three factors P. I_1 and I_2. 27 : 9 : 12 : 16

TABLE 1.

Localised Purple ($PPi_1\ i_1$) and Green-throughout ($ppi_1\ i_1$).

Generation	Number	Characters	
		L. P.	G. T.
Cross (1926)	E.C. II	..	..
Parent	E.C. 424	..	♀
,,	E.C. 421	♂	..
F_1	....	Localised purple	..
F_2	E.C. 711	146	39
,,	E.C. 712	128	61
Cross (1926)	E.C. III	..	..
F_2	E.C. 713	136	40
		410	140

TABLE II.

Purple ($PPI_1I_1I_2I_2$) and Green-throughout ($ppI_1I_1I_2I_2$).

Generation	Number	Characters	
		P.	G. T.
Cross (1929).	E. C. CXVII.		
Parent	E. C. 47		♀
,,	E. C. 477	♂	
F_1	..	Purple	
F_2	E. C. 1504	197	57
Natural Cross (1923)			
F_2	E. C. 20	142	51
,,	E. C. 21	138	50
F_3 (*from E. C. 20 family.*)			
Character of selection.			
Purple	E. C. 257	pure	
,,	E. C. 258	pure	
,,	E. C. 262	pure	
,,	E. C. 266	pure	
,,	E. C. 259	158	51
,,	E. C. 260	138	51
,,	E. C. 261	130	50
,,	E. C. 263	133	48
,,	E. C. 264	148	49
,,	E. C. 265	135	45
F_3 (*from E. C. 21 family.*)			
Purple	E. C. 271	pure	
,,	E. C. 273	pure	
,,	E. C. 267	138	49
,,	E. C. 268	132	51
,,	E. C. 269	138	50
,,	E. C. 270	151	53
,,	E. C. 272	143	60
,,	E. C. 274	158	42
,,	E. C. 275	150	57
,,	E. C. 276	160	47

TABLE III.

Purple ($PPI_1I_1I_2I_2$)—Localised purple ($PPi_1i_1I_2I_2$) and Green-throughout ($ppI_1I_1I_2I_2$) and ($ppi_1i_1I_2I_2$.)

Generation	Number	Characters				
		P.	L. P.	G. T. ($ppI_1I_1I_2I_2$)	G. T.*	(G. T. $ppi_1i_1I_2I_2$)
Natural Cross (1925)		Purple				
F_2	E. C. 61	103	36		40	
F_3						
Character of selection.						
Purple	E. C. 477	pure				
,,	E. C. 483	252	80			
,,	E. C. 478	125		42		
,,	E. C. 479	354		98		
,,	E. C. 485	317		108		
,,	E. C. 486	384		109		
,,	E. C. 475	277	90		126	
,,	E. C. 476	253	92		94	
,,	E. C. 480	260	80		115	
,,	E. C. 481	158	53		69	
,,	E. C. 482	164	57		68	
,,	E. C. 484	153	49		60	
L. P.	E. C. 471		pure			
,,	E. C. 473		pure			
,,	E. C. 469		211			83
,,	E. C. 470		221			81
,,	E. C. 472		327			100
,,	E. C. 474		245			76
G. T.	E. C. 463				All	
,,	E. C. 464				All	
,,	E. C. 465				All	
,,	E. C. 466				All	
,,	E. C. 467				All	
,,	E. C. 468				All	

*Green-throughouts, owing to the absence of degrees of purple pigmentation, are not separable into their component genetic compositions, except when bred out of their simple colour allelomorphs. When so inseparable, they are shown under a bracketed G. T.

This clan E. 61 having been thus genetically analysed, an artificial cross was made between a green-throughout ($ppI_1I_1I_2I_2$) E. C. 994 extracted from family No. E. C. 478 and a Localised Purple $PPi_1i_1I_2I_2$) from E. C. 473, two individuals of known genetic composition from the above table. This cross gave, as expected, a purple plant in the first generation, confirming the bringing together of the intensification factor (I_1) through the green-throughout, and the purple factor (P) through the localised purple.

TABLE IV.

Purple ($PPI_1I_1I_2I_2$). *Dilute Purple* ($PPI_1I_1i_2i_2$) *and Green-throughout* ($ppI_1I_1I_2I_2$) *and* ($ppi_1i_1i_2i_2$).

Generation	Number	Characters				
		P.	Dil. P.	G. T. ($ppI_1I_1I_2I_2$).	G. T. ($ppI_1I_1i_2i_2$).	G. T.
Cross (1929) . . .	E. C. CXX.					
Parent	E. C. 994			♀		
„	E. C. 543		♂			
F_1		Purple				
F_2	E. C. 1579	118	42			51
„	E. C. 1580	133	42			74
		251	84			125
F_3 (*from E. C. 1579 family.*) *Character of selection.*						
Purple	E. C. 1998	pure				
„	E. C. 1999	pure				
„	E. C. 2003	pure				
„	E. C. 1993	103	34			
„	E. C. 2000	90	41			
„	E. C. 2001	120	42			
„	E. C. 2002	79	41			
„	E. C. 1997	127		39		
„	E. C. 1994	53	25			27
„	E. C. 1995	77	28			28
„	E. C. 1996	85	27			27
„	E. C. 2004	135	35			56
Dil. P.	E. C. 2005		pure			
„	E. C. 2006		110				37
„	E. C. 2007		111				42
„	E. C. 2008		151			*	45
G. T.	E. C. 2009					All	

TABLE V.

Purple ($PPI_1I_1I_2I_2$) *and Localised purple* ($PPi_1i_1I_2I_2$).

Generation	Number	Characters	
		P.	L. P
Cross (1927)	E. C. LI.		
Parent	E. C. 563		♀
,, ...	E. C. 851	♂	
F_1		Purple	
F_2	E. C. 1309	39	11
,, ...	E. C. 1310	20	10
Cross (1927)	E. C. LIV.		
F_2	E. C. 1311	167	55
,, ...	E. C. 1312	158	55
,, ...	E. C. 1313	180	63
		564	194

TABLE VI.

Purple ($PPI_1I_1I_2I_2$). *Dilute purple* ($PPI_1I_1i_2i_2$).

Generation	Number	Characters	
		P.	Dil. P.
Cross (1927)	E. C. XLIX.		
Parent	E. C. 543		♀
,, ...	E. C. 297	♂	
F_1		Purple	
F_2	E. C. 1306	187	56
,, ...	E. C. 1307	163	55
Cross (1927)	E. C. L.		
F_2	E. C. 1308	440	136
		790	247

TABLE VII.

Purple ($PPI_1I_1I_2I_2$). *Dilute Purple* ($PPI_1I_1i_2i_2$) *and Localised Purple* ($PPi_1i_1I_2I_2$) *and* ($PPi_1i_1i_2i_2$).

Generation	Number	P.	Dil. P.	Characters L. P. ($PPi_1i_1I_2I_2$). L. P. ($PPi_1i_1i_2i_2$) L. P.	
Cross (1927) . . .	E. C. XLVIII				
Parent	E. C. 302			♀	
,, ...	E. C. 543		♂		
F_1		Purple			
F_2	E. C. 1304	146	48	64	
F_3					
Character of selection.					
Purple	E. C. 1631	pure			
,, . . .	E. C. 1639	pure			
,, ...	E. C. 1640	pure			
,, ...	E. C. 1634	99	36		
,, ...	E. C. 1632	133		36	
,, ...	E. C. 1633	87	32	49	
,, ...	E. C. 1635	68	23	37	
,, ...	E. C. 1636	93	38	54	
,, ...	E. C. 1637	93	42	57	
,, ...	E. C. 1638	104	25	31	
,, ...	E. C. 1641	82	30	39	
,, . . .	E. C. 1642	52	35	36	
Dil. P.	E. C. 1643		pure		
,, ...	E. C. 1644		pure		
,, ...	E. C. 1645		pure		
,, ...	E. C. 1647		pure		
,, ...	E. C. 1646		21		13
,, ...	E. C. 1648		25		10
L. P.	E. C. 1649			All	
,, ...	E. C. 1650			All	

TABLE VIII.

Purple ($PPI_1I_1I_2I_2$)—*Dilute purple* ($PPI_1I_1i_2i_2$)—*Localised-purple* ($PPi_1i_1I_2I_2$), ($PPi_1i_1i_2i_2$),—*and Green-throughout* ($ppI_1I_1I_2I_2$), ($ppI_1I_1i_2i_2$). ($ppi_1i_1I_2I_2$), *and* ($ppi_1i_1i_2i_2$).

Generation	Number	Characters			
		P.	Dil. P.	L. P.	G. T.
Cross (1929) . .	E. C. CXIX . . .	..	..	..	..
Parent . . .	E. C. 993 G. T. ($ppi_1i_1I_2I_2$) .	..	..	..	..
,, . . .	E. C. 543 Dil., P. ($PPI_1I_1i_2i_2$).	..	..	..	..
F_1 . . .	....	Purple	..	..	..
P_2 . . .	E, C, 1577	85	36	49	67
,, . . .	E, C, 1578	99	38	50	53
	Total .	184	74	99	120
	Expected numbers .	201	67	89	120
	Theoretical ratio .	27	9	12	16

$X^2 = 3{\cdot}29$ $P = {\cdot}3$

The results presented above amply confirm the genetic interpretation given in introducing them.

It is interesting to note that the full purple-pigmented type is built up by an accumulation of single factor dominants, the whole of the purple group being marked off from the broad group of green-throughouts, by the presence of a single factor for pigmentation. It is further noteworthy that these greens could be separated into their respective genetic pigment-producing potentials.

SUMMARY.

As in the case of other cereals, purple pigmented plants are dominant to green-throughouts in *ragi*, *Eleusine coracana*, (Gærtn.). Three distinct types of pigmentation, varying in intensity are met with, each showing a single factor advance over the next lower one. Breeding tests have revealed the possibility of classifying the green-throughouts into types of various kinds of purple pigment-producing potentials.

STUDIES IN SORGHUM, I.

ANTHESIS AND POLLINATION.

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(With Plate XLII.)

INTRODUCTION.

Sorghum is the Great Millet. It is extensively grown in India and has special adaptations for its being pre-eminently a crop suited for cultivation under dry conditions. This cereal has attracted the attention of botanists, agronomists, and plant-breeders for a considerable time. With the starting of the Millet Breeding Station in the year 1924, the study of sorghums commenced on a serious footing at Coimbatore and this paper records one aspect of the work, namely Anthesis and Pollination. It is natural to expect that such a delicate process will vary with various seasonal, climatic and regional factors. What is recorded at Coimbatore cannot, therefore, be taken to be of universal application but only as a measure to the delicacy of response in so vital a process. The findings of other workers have been brought under general review and are referred to as occasion arises to parallel the observations at Coimbatore.

MATERIAL.

The observations given below were made on six varieties, in one of which they were pursued in great detail. These were recorded primarily in the years 1927 and 1928, aspects of special confirmatory observations being continued till

1930. References to the new variety *Sorghum margaretiferum* given below are as late as February, 1931. The varieties studied are given below :—

Sorghum Durra—

Chinna-manjal . . .	(A.S. 802)—in detail.
Sen-cholam	(A.S. 841)
Chitrai-vellai	(A.S. 727)
Peria-manjal	(A.S. 44)

S. Roxburghii. var. *hians.*—

Talaivirichan . . .	(A.S. 468)

S. Nervosum—

Irungu	(A.S. 1130)

N.B.—A.S.=*Andropogon Sorghum.*

The "Flag".

The beginning of the reproductive phase in sorghums is the impending ushering out of the "boot", which is the terminal leaf-sheath. Its leaf-blade is the "flag". Prior to the emergence of this boot, the stalk at the top of the plant assumes a characteristic swollenness, unmistakably indicative of the impending emergence of the flag. The boot has its flag to push out and observations made from the commencement of the coming out of the tip of the flag, to its complete emergence, show that it takes about 6 days to do so.

The Emergence of the Boot.

After the flag is out, the emergence of the boot proper begins. Emergence is taken to connote the contact of the ultimate node with the penultimate "junction". The junction is the triangular band of light-coloured, specialised tissue at the meeting place of the leaf-blade and the sheath-top. The boot takes about nine days to emerge. In longer duration varieties there is a correspondingly longer time taken for this emergence. In the case of *S. Roxb.* var. *hians*, it takes more than a fortnight.

The Emergence of the Panicle.

When the boot has emerged, the enclosed ear-head starts to peep out concurrently. It takes 5 days for the base of the ear-head to get clear of the boot. A corresponding increase in the number of days is indicated with long duration varieties, for example, over ten days in the case of *S. Roxb.* var. *hians.*

The Stalk.

After the head is out, its stalk begins to grow and pushes it aloft in about 5 days' time. The length of stalk of the ear-head varies considerably and is a varietal character. In the case of *S. Roxb.* var. *hians*, the emergence of the head leaves little else to come out of the boot. Whereas in *S. Nervosum*, characterised by its long flower-stalk, the extra length is pushed out with greater rapidity and with no appreciable difference in this phase of emergence. In the compact-headed varieties characteristic of the black soils of the Deccan the liberation from the ensheathing boot is effected not so much by the lengthening of the stalk as by a gentle twist at the base of the stalk which dodges the head out and keeps it clear and parallel to the boot-sheath.

The Ear-head.

Before describing the anthesis, a general sketch of the floral units composing the emerged head is given below for the commonest variety *S. Durra*. We have closely followed Prain [1917].

The Panicle.—Panicle usually quite compact, ovoid or ellipsoid, erect or sometimes recurved, 4-6 inches by 2-4 inches ; branches erect, more or less flexuous, rather slender, rough to spinulously ciliolate, particularly upwards, ciliate to sub-villous at the base, the longest up to one-half or a third the length of the panicle, divided from very low down. Racemes compact, tough, about 6 mm. long (in flower), mostly 3- or 4-noded ; joints somewhat stout, flattened, 1 to almost 2 mm. long, whitish-ciliate ; pedicels similar, but still shorter.

The panicle consists of a much furrowed central axis with lateral branches arranged in whorls. Generally 10 whorls are present. Each whorl has 7 to 8 branches except at the extreme tip of the panicle in which they are fewer. Lower whorls bear the maximum number of spikelets in the head.

Mature panicles very dense to compact, rarely more or less loosened owing to the reduction of the primary axis and the consequent sub-digitate arrangement of the branches ; spikelets always densely clustered.

Sessile, bisexual spikelet.—Sessile spikelet rhombic-obovoid, subacute (in flower) ; 5-6 mm. by 3-4 mm ; callus beard scanty ; awned or awnless. Lower glume with a rather conspicuous, greenish, usually strongly nerved tip. Glumes equal, coriaceous, up to beyond onehalf or two-thirds, then papery, unevenly strigillose, particularly

at the tips and sides ; 2-keeled upwards (keels rough), more or less flattened out and very broad to rotundate when mature with the tips worn off.

Glume I.—Encloses Glume II ; edges hairy ; thick and opaque ; apical portion 9-nerved ; nerves green.

Glume II.—Encloses Glume III ; edges hairy ; thick and opaque ; has a central ridge ; seven-nerved of which three are very prominently green.

Glume III.—Encloses Glume IV ; hyaline ; 2-nerved ; nerves colourless.

Glume IV.—Hyaline ; bears the palea ; bears the awn in awned heads and a vestige of the awn (which does not show itself out) in awnless ones. Where the awn starts 3 nerves coalesce. The 3 nerves are colourless but are brown where they unite.

Palea.—Situated opposite to Glume IV ; a long narrow strip of transparent tissue ; no nerves ; hairy.

Stamens.—Three —a pair and an odd opposite ; anthers 3-4 mm. long ; anthers open by apical slits.

Ovary.—One ; two stigmatic branches ; styles terminal, laterally exserted ; feathery stigmas start from the middle of the style.

Lodicules.—Two ; fleshy ; ciliate.

Unisexual, pedicelled spikelets.—The pedicelled spikelet persistent, lanceolate to linear-oblong, sub-acute, up to 6 mm. long, permanently herbaceous.

Glume I.—Thick and opaque ; 9-nerved ; nerves green ; encloses Glume II.

Glume II.—Thick and opaque ; 8-nerved ; nerves green ; encloses Glume III.

Glume III.—Hyaline ; 2-nerved ; nerves colourless ; encloses Glume IV.

Glume IV.—Hyaline ; bears a palea ; 2-3 nerves meeting at the apex ; no awn.

Palea.—Situated opposite to Glume IV ; hyaline ; hairy ; no nerves.

Stamens.—Three ; anthers 3-4 mm. long.

Lodicules.—Two ; fleshy ; ciliate.

The Order of Anthesis.

As described above, the panicle consists of a central stalk with a number of lateral branches which bear the spikelets. The topmost spikelet in each branch opens first and the flowering spreads down gradually till all the spikelets in the branch have flowered. Among the branches, this process proceeds from top to bottom. This general orderliness from top to bottom prevails except that when

more than half way through, a sort of second wave of anthesis, representative of such male flowers as have anthers, starts at the top and obtrudes into this scheme.

First Flowering.

The head having emerged, the theatre is clear for anthesis. The date on which the first anthers come out will vary according to the general weather and the vigour of the plant. In the observations under report it took five days to do so. Other instances have shown that this could occur in one or two days. There is a corresponding delay up to a week in the case of longer duration varieties.

Period of Flowering in a Head.

The number of flowers opening in a ear-head varies from 2000-4000. The maximum time taken for one ear-head to complete its flowering is 8 days. Lingering flowers may appear even on the ninth day. The maximum number of flowers to open is in the middle of this period between the third and sixth days.

March of Flowering in a Day.

Ball [1910] and Vinall [1926] working in America record that flowers open " in the early morning hours ". They do not specify the hour. Nafziger [1918] at Kansas states that " the stamens do not emerge during the heat of the day but emerge freely at night ". Kōrnicke [1885] reports that flowering begins in the morning between 8 A.M. and 9 A.M. and that it may continue till the evening. According to Patels [1929] in Gujarat, flowering is confined to the forenoon, in some cases commencing even at 4 A.M. Graham [1916] at Nagpur finds that the opening of flowers is between 11 P.M. and 4 P.M. the next afternoon, with minor variations. Working in Bellary, Ramanathan [1924] says that the flowering period is between 1 A.M. and 4 P.M.

Sorghum flowers, as observed at Coimbatore on varieties of *S. Durra*, *S. Roxb.* var. *hians* and *S. Narvosum*, commence opening their flowers at midnight. The commencement of the anthesis is not uniform but varies from 12 midnight to 2 A.M. generally. The opening continues till 8 A.M. usually and may get prolonged to 10 A.M. at the most. In the case of a red-grained, compact-headed variety of *S. Durra* type, the opening was as late as 4 A.M. stopping at 8 A.M. The condition of the weather has naturally a modifying influence on this general tenor. Wet weather delays flowering, and after flowering, delays the opening of anthers.

The only instance of the opening of flowers observed to commence in the day is in the case of *S. margaretiferum*, a sorghum from Sierra Leone, in which flowers were observed to open from 8 A.M. to 4 P.M. This is a new introduction and any possible changes in its floral habits will be watched with interest.

The following table gives an idea of the anthesis-energy as distributed in the daily period.

	A.M. 0-2	A.M. 2-4	A.M. 4-6	A.M. 6-8	A.M. 8-10	Total number of flowers	Total number of days of flowering
							Days
S. Durra.							
Sen-cholam . . .	..	12	2,117	14	..	2,143	9
Chinna-manjal . .	..	3,039	89	30	6	3,164	8
Chitrai-vellai . .	944	2,019	424	95	27	3,509	7
Peria-manjal . .	1,620	1,693	238	13	..	3,564	9
S. Roxb. var. *hians.*							
Talaivirichan . .	3,235	850	17	5	..	4,107	8
S. Nervosum.							
Irungu . . .	1,511	365	14	9	2	1,901	9

It will be noticed that the biggest rush of flowering and the major portion of it is within the first three hours of initial opening.

Anthesis in a Typical Flower.

Detailed observations on anthesis in an individual flower are recorded below in the case of a typical flower. A stop-watch was used.

Hours.	Mins.	Secs.	
2	..	..	A.M.—Glumes begin to open.
2	1	..	„ —Staminal column just visible.
2	1	30	„ —Staminal column completely visible.
2	2	..	„ —Stamens separate.
2	2	30	„ —First anther tilts down.
2	2	40	„ —First anther pendent.
2	3	..	„ —Other two anthers tilt down.
2	3	20	„ —Other two anthers pendent.
2	18	..	„ —Glumes begin to close.
2	45	..	„ —Glumes completely close.

In the case of longer duration varieties there is a tendency for this period of 45 minutes to extend. In *S. Roxb.* var. *hians* the period takes over 70 minutes. Graham and Ramanathan, however, record that glumes remain open for 2 to 4 hours.

PLATE XLII.

SORGHUM—ANTHESIS.

In the detailed observations made on six different varieties in two seasons, it is remarkable that in the three dry-land varieties observed the pendency of the three anthers was one at a time as against the two after one of irrigated varieties.

General Anthesis.

The glumes begin to open gradually due to the pressure exerted by the swelling lodicules. The lodicules swell to over twice their size during the opening of the flower.

Körnicke observes that the stamens and stigmas protrude simultaneously. Kirchner, Graham [1916], Ramanathan [1924] and Patels [1929] say that the stigmas come out first, sometimes as early as 15 to 36 hours before the appearance of the stamens. The last, however, record that in certain Egyptian varieties grown at Surat, the order is reversed. At Coimbatore, the anthers appear first in a column enclosing the two stigmatic branches which are adpressed to their inner faces.

Graham records that the two lateral stamens fall out first and then the posterior one. Patels say that one anther drops out first and the other two (though not always simultaneously) later. According to our observations, the end-anther of the pair tilts down first releasing the glistening stigmas which, after rotating in one plane, spread out. These remain outside the glumes at the angles even after the glumes close. Later the two other anthers tilt down and become pendent.

The filament of the anther, which drops out first, elongates very rapidly and soon the anther bends to one side and is pendent. The other two anthers remain together. The filaments in these do not grow so rapidly as in the first one, but lengthen out gradually and occupy a pendent position opposite to the first anther. The length of staminal filament (pre-opening) is 2 mm. Its length, after the opening of the flower, is 14—15 mm. except for a noticeable shortage in *S. Roxb.* var. *hians*, in which it averages 7—10 mm.

It is found in the case of anthers resting on lower flowers that their filaments are not so long as those of anthers hanging freely.

This free exsertion and dangling of the anthers is the general rule (Plate XLII), though in the case of a white-grained, compact-headed variety (A. S. 1044) the anthers do not exsert freely but just emerge and remain as it were stuck up to the tops of the gaping glumes. At the stage when all the three anthers are pendent the glumes attain their maximum opening which is about 35°.

Körnicke, Kirchner and Ramanathan find that the dehiscence of anthers takes place after they become pendent. Graham observes that it could take place at earlier stages also in addition. At Coimbatore the dehiscence of anthers is simultaneous with the opening of glumes. The freed pollen dusts the adjacent

stigmas. Though this is the general rule, in some cases it is found that the anthers dehisce after they become pendent or during the bending of the filaments. Though the anthers dehisce right at the opening of the flower, all the pollen is not shed simultaneously. In the morning the stamens that had opened earlier in the night are still found to contain some more pollen.

The glumes begin to close slowly and do not open again when once they close. The first signs of drying are found in the anthers at the tips at about 10 A. M. The pollen-laden stigmas continue to be fresh. They begin to dry up by noon. Complete drying up of both takes place by next morning.

Pedicelled flowers.

As we have already said, sorghum grains are borne on hermaphrodite flowers. Normally every one of these hermaphrodite flowers has attached to it and in the nature of a twin at least one-pedicelled flower. These flowers are complete in floral envelopes or occasionally mere vestiges of floral parts. When present they are not usually obtrusive but are in the nature of a padding between hermaphrodites. In a few varieties, however, they are markedly noticeable and give the earhead a prickly look. Often there are two-pedicelled flowers, one on each side of the hermaphrodite. This two-ness is confined to the terminal hermaphrodite flowers. Very rarely hermaphrodites happen to be alone without any pedicelled flowers attached to them. Hermaphrodites with three-pedicelled flowers are a rarity.

Almost all the pedicelled flowers are barren. Occasionally in the end spikelet, where they happen to be in twins, odd flowers bear anthers. In rare varieties, even sterile hermaphrodites are occasionally met with.

Two-pedicelled spikelets being confined to the terminals, the shape of the earhead and its compactness have a relationship to the incidence of these twin-pedicelled flowers. An examination of the three broad groups, *S. Durra*, *S. Roxb.* var. *hians* and *S. Nervosum*, show the differences presented below, the arrangement being from the compact downward.

	Percentage of hermaphrodites with two-pedicelled flowers to total hermaphrodites	Percentage of pedicelled spikelets with anthers to total pedicelled spikelets
S. Durra— (Periamanjal, etc.)	46	2·2
S. Roxb. var. *hians*— (Talaivirichan)	34	*Nil*
S. Nervosum— (Irungu)	29	*Nil*

It should be noted that this incidence of antheriferous pedicelled spikelets recorded above is borne out by Patels in Gujarat, whereas at Bellary, Ramanathan finds such flowers in the loose-headed types only.

Anthesis of Pedicelled Spikelets.

As has already been mentioned, almost all pedicelled flowers are abortive. Rarely one or both of the terminal two-pedicelled units may bear anthers. These anther-bearing pedicelled flowers, in the rare cases in which they do exist, are very few in numbers, 6, 18 and 141 being the number present in the three cases noted. Such flowers start opening at about the close of the main wave of the anthesis of hermaphrodite flowers. This accounts for the fresh patches of yellow that appear on the background of the withered old mass of anther-sacs of the first wave. When the anthers do come out, they do so simultaneously and dehisce, not one after the other as in the case of the heramphrodites. The glumes keep open for a very long time, sometimes for 12 hours.

Long (1930), after an extensive examination of the spikelets of *Andropogon halipensis* and *A. S.* var. *sudanensis*, comes to the conclusion that the aborted pistil of the pedicelled flower suggests that it once had a perfect flower. The loss has, therefore, been of the pistil with the retention of the anthers. A study of the pedicelled spikelets in sorghum takes this observation to its logical conclusion and explains the emptiness of many of these pedicelled spikelets as possibly due to the cumulative effect of an inoperative superfluous existence which the selective forces under cultivation tended to accentuate.

Pollination in Nature.

The general trend of this study is to assist us to evaluate the factors contributing to fertilisation. The broad findings are that at Coimbatore optimum conditions prevail for fertilisation of flowers one with the other within the earhead. Instances of pollination within the flower with its own pollen seem remote. In a community of single-stalked heavy heads with a flag easily set in motion, it is quite within possibility that pollination between earheads both through physical contact and through wind-borne pollen might take place. Between adjacent varieties the extent of natural crossing at Coimbatore in varieties grown under irrigation in summer (*S. Darra*) has been determined at 7 per cent. [Rangaswami Ayyangar, 1924].

In this connection it will be interesting to review the findings of other workers. C. R. Ball, working in America, recorded that in adjacent rows of different varieties flowering on approximately the same dates, as much as 50 per cent. is cross-fertilised. In the year 1916 Graham, working at Nagpur, estimated the proportion

of natural cross-fertilisation in a loose-panicled type as 6 per cent. and in a type with a compact panicle as 0·6 per cent. In one of his varieties as much as 20 per cent. occurred. In 1919 Karper and Conner [1919], working in Texas (U. S. A.), got an average of 6 per cent. In 1922 Kottur and Kulkarni [1922], working at Dharwar, experienced a range of crossing from *nil* to 12 per cent., with the largest frequency at 2 per cent. In 1924 Ramanathan, working at Bellary, gives the range of cross-pollination from 1 to 35 per cent. In 1929 Patels, working at Surat, note that natural crossing may go up to 40 to 50 per cent.

Behind this wide range of percentages in natural crossing the broad fact remains how liable sorghum is to taint from foreign pollen. In any scheme of pushing improved varieties and maintaining them in a state of improvement, special measures in the organisation of the distribution and maintenance of seed-supply are indicated.

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STUDIES IN INDIAN TOBACCOS.

No. 6. THE IMPROVEMENT OF INDIAN CIGARETTE TOBACCO BY HYBRIDIZATION.

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(With Plates XLIII to XLVIII.)

I. INTRODUCTION.

The production of cigarettte tobacco has been the subject of a previous communication [Shaw and Kashi Ram, 1929], and it has been shown that a bright leaf of a suitable colour and texture can be produced in India by flue-curing. Up to the present, however, none of the indigenous tobaccos have been found suitable for the poduction of a good quality cigarette tobacco by flue-curing and the varieties which have proved successful bave all been exotic tobaccos the seed of which has been imported from America. The introduction and acclimatization of an exotic crop is a matter which generally presents difficulty, and in northern India the chief obstacle to the success of a plant from a more temperate zone is usually the short growing season. In the case of tobacco in Bihar, transplanting is generally carried out about the end of September and the crop should reach its maximum development about the end of November, after which the rapid fall in temperature soon brings growth to a standstill. This gives a very short growing season which is not, as a rule, long enough to allow an exotic tobacco to reach its full growth.

One of the most successful of the imported varieties has been that known as Adcock and in the case of this type it has been found that sowing and transplanting

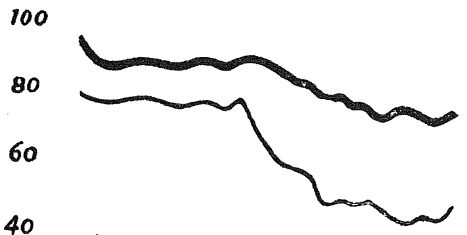
about 2 weeks earlier than the local practice is generally an advantage as it gives the crop a longer growing season. An experiment was conducted in which Adcock tobacco was sown at intervals of a fortnight from the 15th July to the 15th August. Three sowings were made and transplanted under identical conditions of culture and manure. The growth periods of each sowing were :—

1st sowing . . .	3 months.
2nd „	2½ „
3rd „	2 „

The maximum growth was obtained by the first sowing and the smallest growth by the third sowing. The photograph and the temperature curves (Plate XLIII) indicate that the decrease in the length of the growing period as the time of sowing becomes later is to be correlated with the fall in temperature.

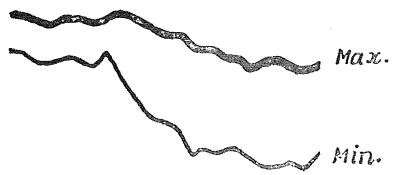
There are, however, certain disadvantages in transplanting tobacco very early in Bihar. These are chiefly due to the fact that tobacco which is growing vigorously in the warm moist climate which prevails in September-October is more liable to damage by disease than that transplanted at the normal time. The disease which is mostly responsible for this damage is the leaf spot disease caused by a fungus *Cercospora nicotianae*. Attempts have been made to grow tobacco in Bihar in the rains, sowing and transplanting being done about three months earlier than normal. While the scale on which this has been tried is so far limited, the experience gained indicates that the incidence of leaf spot disease is likely to prove a limiting factor in the cultivation of tobacco in the rains in Bihar. In addition to the damage sustained by the mature plant from leaf spot disease, early sowing exposes the seedlings to a longer and more severe spell of monsoon conditions and this generally results in an increased mortality in the seed-beds from surface wash, insects and " damping off ". These difficulties have already been touched upon in a previous communication.

Considering all the above difficulties in the culture of an exotic tobacco such as Adcock, it appeared advantageous to search for a type which would combine the curing qualities of Adcock with the hardiness, yielding power and quick growth of an indigenous type. A large number of curing tests with indigenous types have shown that none of the native varieties possess the power of producing a cigarette leaf equal to that given by some of the exotics and it was suggested that crossing an exotic tobacco with an indigenous type offered the best chance of obtaining a tobacco with the required properties. The parents chosen for this cross were Adcock and the variety known as Pusa Type 28, and the cross was made in the year 1924. The latter is an indigenous tobacco which perhaps comes nearer in quality to a cigarette leaf than any other type which is native to India. Pusa Type 28 was first isolated by the Howards [1910] from a mixed collection of Indian tobaccos and is



Sown on 15th July and transplanted on 1st September. 3 months' growth.

Sown on 1st August and transplanted on 15th September. 2½ months' growth.



Sown on 15th August and transplanted on 1st October. 2 months' growth.

THE GROWTH OF ADCOCK—SOWN AT THREE DIFFERENT INTERVALS.

PLATE XLIII.

described in a memoir. It has spread over Bihar and prior to the introduction of flue-curing and the success of imported varieties it was the best tobacco available for the production of cigarette leaf in Bihar.

II. Technique of Crossing.

As has been stated by Mrs. Howard [1913], the actual operation of crossing is easy in tobacco.

In the young bud, the anthers remain much below the stigma. Just before the flower opens a very rapid growth takes place in the filament, which causes the anthers to be pushed up past the stigma, and in almost all cases the anthers come in direct contact with the stigma while passing upward. Before the flower opens, the anthers burst and the stigma becomes receptive ; thus self-fertilization is the natural habit of the plant and cross-fertilization is occasional.

Crossing consists of emasculating flowers of the maternal parent and pollinating them by hand from selected protected flowers of the paternal plant. The right stage for the emasculation of tobacco flowers at Pusa is just when the flower bud assumes a pinkish tinge or about eighteen hours before the anthers begin to dehisce. Anthers generally begin to dehisce and shed their pollen at about 12 o'clock in the morning. In emasculation the corolla tube is split up very carefully with a scalpel, from a little over the calyx right up to the lobes and by gently pushing back the corolla the stamens and the pistil are fully exposed. The anthers with a small portion of their stamens can then be easily removed. To avoid the risk of selfing, special care is taken to remove the anthers before they dehisce, and also to sterilize all the instruments with rectified spirit before each operation. As it had been observed that pollen grains of tobacco flowers keep alive for several weeks, the cut anthers must not be allowed to stick to any of the operated flowers or panicle. In order to protect the emasculated flowers from contamination with a foreign pollen, all such flowers are covered with parchment paper bags and the latter tied up with a soft copper wire at the base. The flowers of the pollen parent (male parent) must also be protected under bag. After emasculation the stage at which the stigma becomes receptive can easily be detected by the rapid change in the colour of the corolla tube from a brickish red to a magenta or deep pink colour and also by the appearance of a viscid sticky fluid on the surface of the stigma. For pollination, only the pollen from those flowers that have been especially protected under paper bags for the purpose is used. In pollination the method of taking one stamen at a time and gently rubbing the burst anthers over the stigma proved a better method than that of applying pollen to the stigma with a camel hair brush. After pollination it generally

takes about a week to form a capsule and the developing capsules can easily be seen through the parchment paper bags. The paper bags are removed after the capsules have grown a little more than the size of a pea seed. The cross-fertilized capsules are frequently visited and the lateral buds are trimmed off.

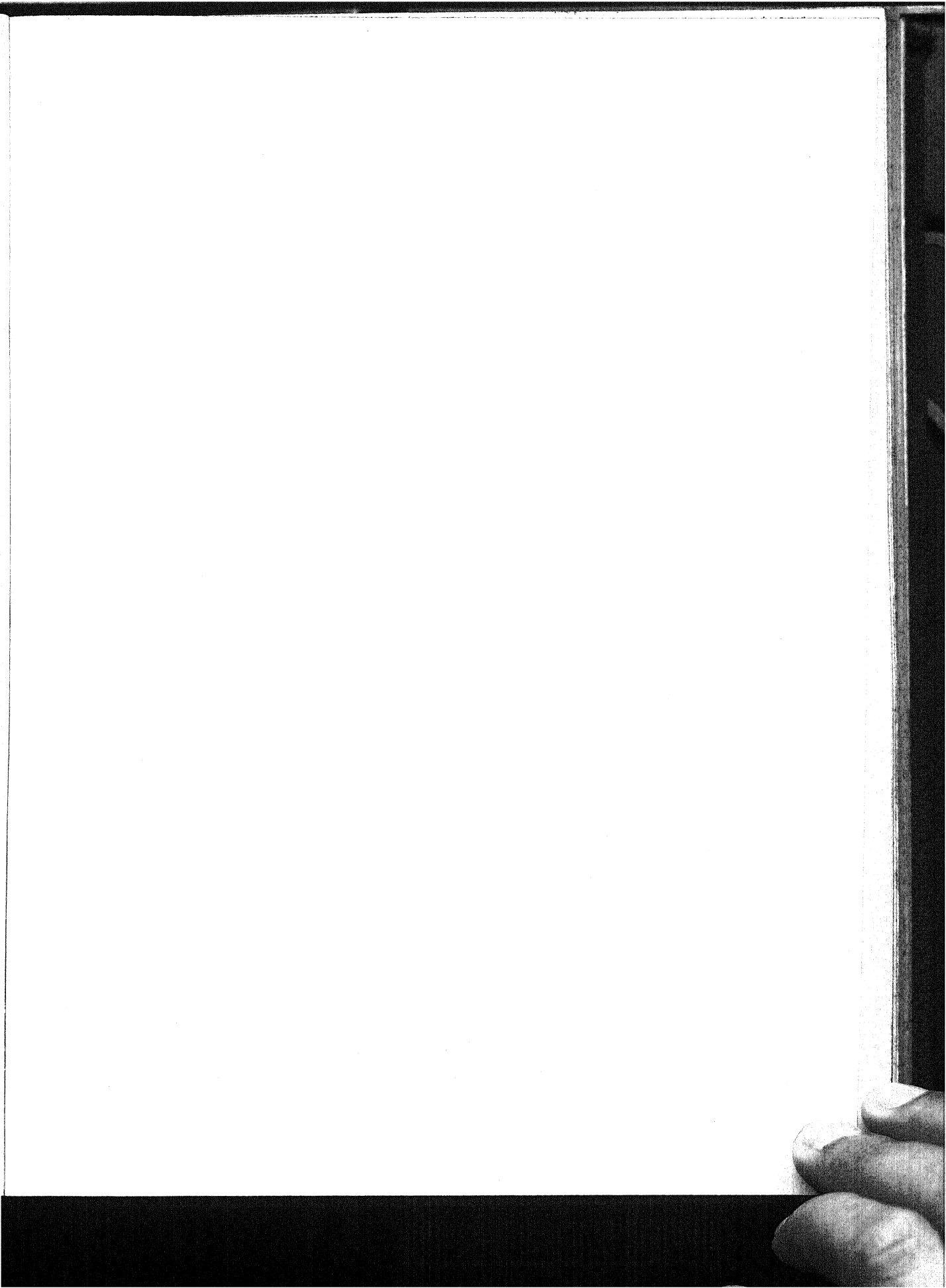
Description of the parents.

" Type 28 Parent, Howard and Howard [1910]. Plants early, tall ; lower internodes short, upper long. *Leaves* sessile, inserted at an angle of 45°, and bent downward from the centre of the leaf, amplexicaul, decurrent, decurrency very narrow ; elliptical, lamina much narrowed in the basal third of the leaf ; apex acuminate ; secondary veins arise at an angle of 45° ; margin very undulate ; surface slightly puckered, lamina raised between the secondary veins giving the appearance of folds or ridges ; leaf not fully expanded but folded on the mid-rib ; colour dark green ; texture thick and rough ; average length 50 cm. ; ratio length/ breadth 2·5. *Inflorescence leaves* lanceolate. *Inflorescence* much raised on long slender branches which are somewhat spreading in habit. *Flowers* sparse, colour deep pink which does not fade. *Calyx* tubular, inflated a little less than half the length of the corolla ; teeth short and acute. *Corolla* with an orifice of 8 mm. in diameter, tube fairly broad, the transition between the tube and the dilated portion gradual ; limb divided to about half its depth with folds at the junction of the lobes ; lobes rounded at the base ; apical points short. *Capsule* a little longer than the persistent calyx, cylindrical ; apex blunt.

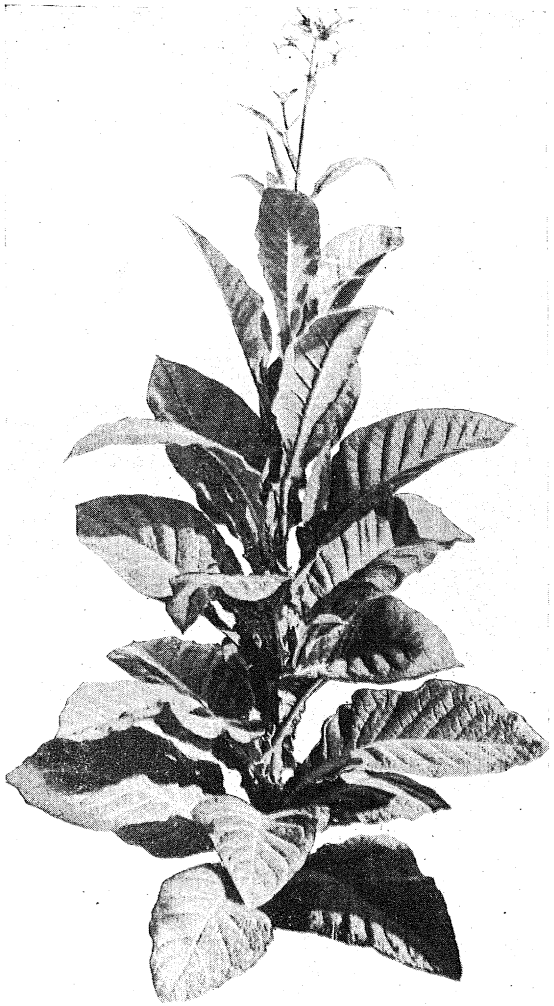
The anthers burst in the bud when they are just above or level with the stigma. "

Adcock Parent. Plants early, medium in height ; internodes medium, leaves borne at an equal distance on the stem. *Leaves* sessile, inserted at an angle of about 60°, amplexicaul, decurrent ; elliptical, lamina narrowed at about 10 cm. from the base and bent downward at the apex ; apex acute ; secondary veins arise at an angle of 50° ; margin wavy, recurved with occasional irregular undulations especially at the base ; surface flat ; colour dark green ; texture thin ; average length 60 cm., ratio length/breadth 2·2. *Inflorescence leavees* lanceolate. *Inflorescence* open and well raised, side branches grow as tall as the main axis. *Flowers* pink, fading to light pink. *Calyx* long, tubular ; teeth long and acute. *Corolla* about 8 mm. in diameter ; tube broad ; the transition between the tube and the dilated portion gradual ; limb slightly divided with folds at the junction of the lobes ; lobes rounded towards the base. *Capsule* about 2/3 covered with the persistent calyx, conical ; apex pointed.

Anthers burst before the flower opens. In the fully open flowers the anthers and stigma are just opposite the orifice.



TYPE 28_PARENT.



TYPE 28 × ADCOCK F.

ADCOCK PARENT.

III. The F_1 Generation.

About fifty plants of the F_1 were grown in the year 1925. In raising the seedlings of the F_1 and the various hybirds subsequently, every possible care was taken to guard against contamination of the seeds. The details of all such precautions have already been described in some of the previous papers on tobacco hence they need not be repeated here.

In general vigour, the F_1 plants were intermediate between the two parents and neither of the parents was completely dominant over the other.

Description of the F_1.

Type 28 × Adcock F_1. Plants earlier and taller than either parent; internodes long, leaves borne at an equal distance on the stem. In general habit the plants were intermediate between both the parents. *Leaves* sessile, inserted at an angle of 90°, amplexicaul, decurrent, decurrency broad; elliptical, lamina narrowed at about 10 cm. from the base and bent downward from the middle; secondary veins arise at an angle of 50°, apex acute; margin wavy; surface smooth; colour light green; texture thick; average length 60 cm., ratio length/breadth 2·0. *Inflorescence leaves* elliptical to lanceolate. *Inflorescence* open and well raised above the leaves, side branches grow as tall as the main axis. *Flowers* light pink, fading to a lighter shade. *Calyx* globular and much inflated, less than half the length of the corolla; teeth short and acute. *Corolla* with an orifice of 8 mm. in diameter; tube broad; the transition between the tube and the dilated portion abrupt; limb undivided with slight folds at the junction of the lobes; apical points short and pointed. *Capsule* nearly 2/3 covered with the persistent calyx, conical; apex pointed.

Anthers burst before the flower opens, and are well above the stigma. In the fully-open flowers the anthers reach the orifice and the stigmas remain a little below the orifice.

The two parents used for this cross and the F_1 plants are shown on Plate XLIV.

IV. The F_2 Generation.

In order to obtain all possible combinations of factors and also a fair percentage of plants resembling the parents in F_2 the growing of a very large population was essential. The selfed seeds of one F_1 plant were sown and a population of about 4,000 plants was therefore grown as F_2 in the year 1926.

The main object in this hybridization work was to produce a variety of tobacco which while retaining the hardy growing characters of an indigenous variety might also be better in quality from the point of view of cigarette manufacture.

The parents used in this cross were selected rather for their economic qualities than as types with definite and clear cut contrasting characters which would afford an easy study of the problems of inheritance. The study of inheritance in this paper has therefore been limited to four quantitative characters which are of economic significance. The characters studied were :—

1. Period of flowering.
2. Height of plants.
3. Number of leaves per plant.
4. Breadth index of the leaves.

Period of Flowering. This was determined by counting the number of days from the date of sowing the seeds up to the day of the appearing of the first flower on each plant.

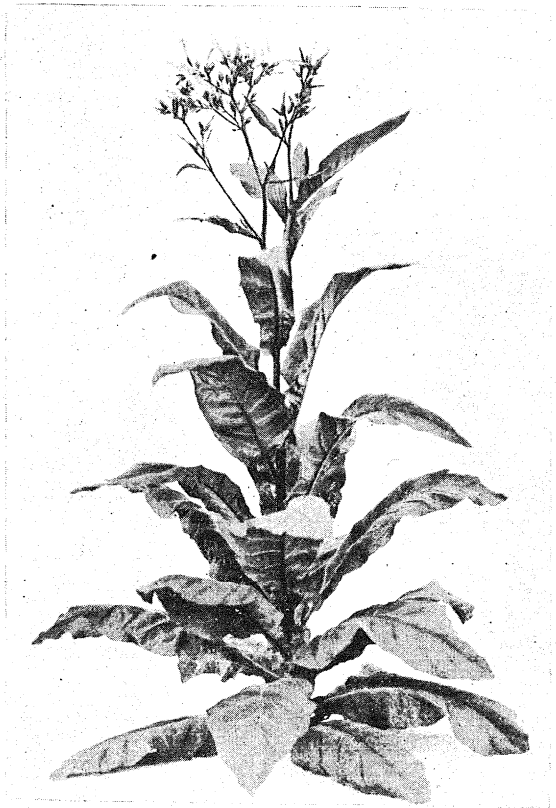
Height of plants. The height was measured from the point where the root begins on the stem, to the terminal capsule on the plant. The terminal capsule generally appears at a point beyond which practically no growth takes place.

Number of leaves per plant. This was determined by actual counts. In counting the number of leaves, the plant had to be uprooted, the roots were trimmed short to the stem, and after washing the base of the plant all the leaf scars from top to bottom on the stem were counted.

Breadth index of the leaves, [Hays, East and Beinhart, 1913].—The size of the leaf is greatly influenced by the environment, therefore the shape of the leaf, which is much less subject to environmental modifications, was made use of. The shape of the leaf was determined by dividing the breadth by the length of the leaf and expressing the result in per cent.

From the F_2 population about 200 promising hybrids were selected and these were selfed. The seed of each selfed single plant was sown separately the following season as F_3. Out of these 200 hybrids only ten hybrids (Plates XLVI, XLVII and XLVIII) that were found varying within narrow limits, practically like the original parents were retained and the rest were discarded. The data collected for each of the hybrids retained, show that they are breeding true. In order to test their purity further some of these hybrids have been grown on an extensive scale and the results so far obtained show that they have become fixed in their characters.

H. 1 (124).

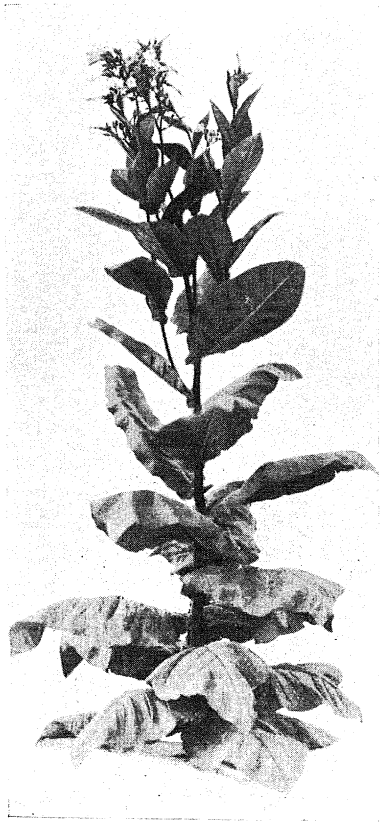


H. 2 (164).

H. 4 (150).

PLATE XLVI.

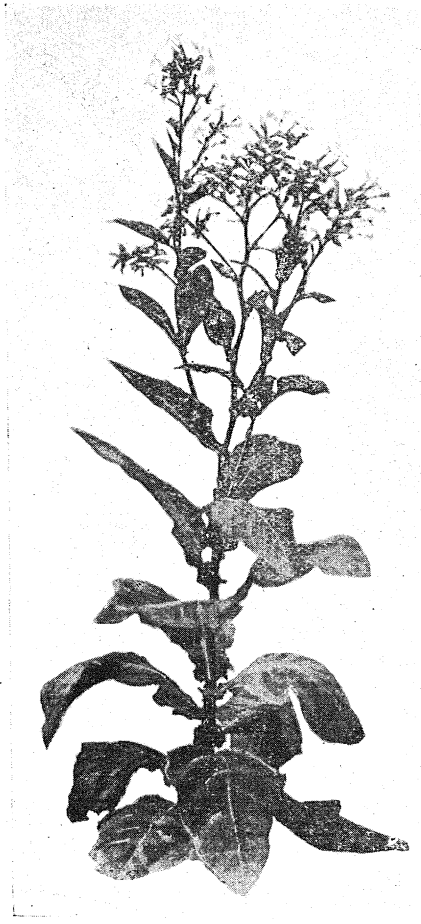
H. 3 (171).



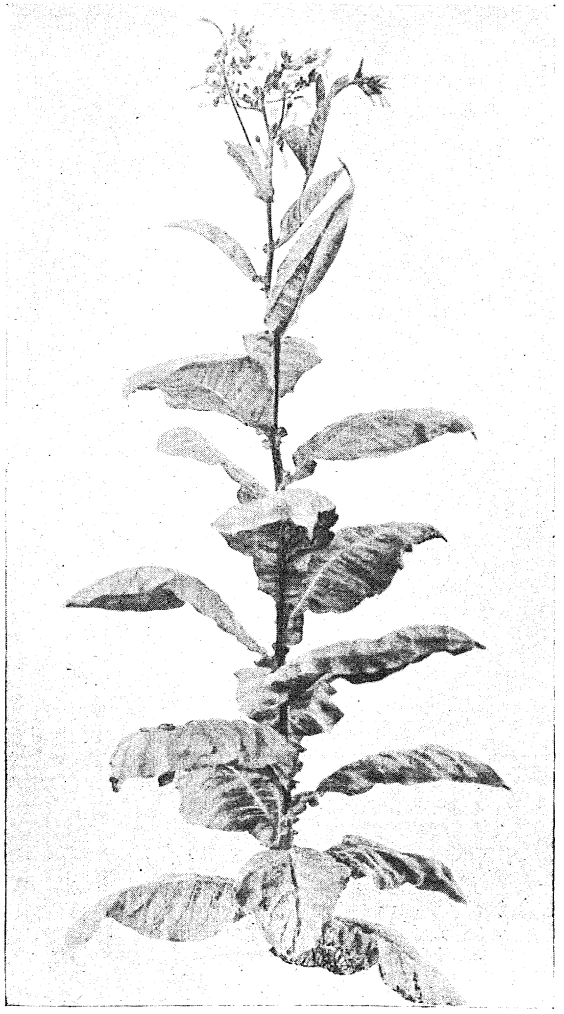
H. 5 (102).

H. 6 (142).

H. 7 (92).



H. 8 (177).



H. 9 (156).

H. 10 (140).

PLATE XLVIII.

TABLE I.

Frequency distribution of flowering days in a cross betweeen Type 28 and Adcock.

No.	Class centres in days																			Total No. of plants	Mean	Standard deviation	Co-efficient of variation
	85	88	91	94	97	100	103	106	109	112	115	118	121	124	127	130	133	136					
Adcock Parent . . .	..	..	..	..	..	..	7	7	14	16	13	7	..	..	..	..	..	..		64	110·95±·37	4·42±·26	3·98±·24
Type 28 Parent . . .	..	..	..	..	..	..	..	..	3	5	6	7	9	12	8	7	3	..		60	121·75±·56	6·41±·39	5·26±·33
Type 28 × Adcock F_1 . .	..	..	..	..	..	..	7	11	14	12	6	3	1	..	..	..	..	..		54	109·06±·40	4·36±·28	3·97±·26
Type 28 × Adcock F_2 . .	22	38	48	85	45	79	37	42	42	16	12	20	11	..	..	..	..	..		497	99·67±·27	8·89±·19	8·92±·19
Type 28 × Adcock H.9 (156) F_3	..	..	..	..	3	9	9	15	10	7	1	..	..	..	..	..	..	..		54	105·49±·40	4·42±·29	4·19±·27
H.4 (150) F_3	..	..	..	..	..	1	3	10	12	5	5	3	3	2	..	..	..	..		44	110·83±·59	5·83±·41	5·26±·38
H.5 (102) F_3	..	..	..	..	..	2	5	16	12	6	6	5	2	1	..	..	..	..		55	109·75±·49	5·47±·32	4·98±·32
H.8 (177) F_3	..	..	..	..	..	2	2	7	8	11	6	5	4	3	2	..	..	..		50	112·84±·62	6·58±·44	5·83±·39
H.2 (164) F_3	..	..	..	..	..	..	..	1	6	8	13	19	4	2	..	..	..	..		53	115·57±·36	3·91±·26	3·38±·22
H.1 (124) F_3	..	..	..	..	..	..	..	2	4	4	5	13	7	7	4	3	..	..		49	118·75±·59	6·08±·41	5·12±·35
H.6 (142) F_3	..	..	..	..	..	..	..	2	5	5	6	2	..	..	..	..	..	..		20	112·15±·52	3·45±·37	3·07±·33
H.3 (171) F_3	..	..	..	..	..	..	..	..	2	6	7	12	9	8	4	3	..	..		51	119·41±·51	5·35±·36	4·48±·30
H.10 (140) F_3	..	..	..	..	..	..	..	..	..	3	4	10	6	5	4	..	..	..		32	119·68±·52	4·36±·37	3·64±·31
H.7 (92) F_3	..	..	..	..	..	..	..	..	..	..	..	2	3	7	11	12	3	3		41	127·60±·45	4·30±·32	3·37±·25

TABLE II.

Frequency distribution for heights of plants in a cross between Type 28 and Adcock.

No.	Class centres in centimetres													Total No. of plants	Mean	Standard Deviation	Co-efficient of variation
	115	130	145	160	175	190	205	220	235	250	265	280	295				
Adcock Parent . . .	..	..	11	34	15	1	..	..	..	..	..	..	..	61	161·35± ·92	10·65± ·65	6·60± ·40
Type 28 Parent . . .	..	..	..	7	30	19	2	..	..	..	..	..	..	58	179·05± ·96	10·86± ·68	6·06± ·38
Type 28 × Adcock F_1 . .	..	..	..	..	..	2	23	17	6	4	..	..	..	54	215·80±1·3	14·65± ·95	6·79± ·44
Type 28 × Adcock F_2 . .	..	..	8	35	81	94	104	73	52	25	18	8	2	500	204·40± .39	20·60± ·63	14·48± ·31
Type 28 × Adcock H·2 (164) F_3	2	18	27	5	..	..	..	..	..	..	..	..	..	52	140·05± ·99	10·58± ·70	7·55± ·50
H·5 (102) F_3	..	10	25	15	..	..	..	..	..	..	..	..	..	50	146·50± ·99	10·44± ·70	7·12± ·48
H·3 (171) F_3	..	2	15	26	6	..	..	..	..	..	..	..	..	49	155·95±1·06	10·96± ·75	7·03± ·48
H·6 (142) F_3	..	..	..	3	4	9	4	..	..	..	..	..	..	20	185·50± ·22	14·27±1·52	7·69± ·82
H·4 (150) F_3	..	..	9	22	11	..	..	..	..	..	..	..	..	42	160·75±1·06	10·22± ·75	6·36± ·47
H·7 (92) F_3	..	..	..	4	16	15	4	..	..	..	..	..	..	39	182·20±1·38	12·32± ·94	6·76± ·52
H·1 (124) F_3	..	..	..	..	6	15	13	10	..	..	..	..	..	44	199·15±1·51	14·87±1·07	7·47± ·54
H·9 (156) F_3	..	..	..	..	7	21	20	2	..	..	..	..	..	50	195·10±1·09	11·46± ·77	5·87± ·39
H·8 (177) F_3	..	..	..	..	13	23	12	..	..	..	..	..	..	48	189·70±1·05	10·76± ·74	5·67± ·39
H·10 (140) F_3	..	..	..	..	3	16	9	3	..	..	..	..	..	31	195·85±1·43	11·76±1·01	6·00± ·52

TABLE III.

Frequency distribution of number of leaves per plant in a cross between Type 28 and Adcock.

No.	Leaf numbers																															Total No. of plants	Mean	Standard deviation	Co-efficient of variation
	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56				
Adcock Parent	..	..	..	..	..	..	13	19	11	11	4	2	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	60	31·67±·11	1·31±·08	4·14±·25
Type 28 Parent	..	..	..	..	..	..	4	5	6	7	7	10	9	6	2	1	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	57	34·15±·20	2·28±·14	6·67±·42
Type 28 × Adcock F_1	..	..	..	..	..	..	..	..	4	4	..	4	8	15	10	4	1	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	50	35·54±·16	1·70±·11	4·78±·32
Type 28 × Adcock F_2	..	..	1	1	3	5	7	16	16	25	25	25	30	42	42	41	39	33	28	25	24	17	10	10	10	10	4	3	3	1	1	2	1	500	39·09±·15	5·21±·10	13·33±·28
Type 28 × Adcock H. 3 (156) F_2	27	21	1	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	49	24·47±·04	0·46±·03	1·88±·13
H. 8 (177) F_2	..	..	11	12	12	6	5	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	46	27·61±·12	1·24±·08	4·49±·31
H. 2 (164) F_2	..	..	..	..	1	1	11	14	13	7	4	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	51	31·45±·12	1·31±·09	4·13±·27
H. 5 (102) F_2	..	..	..	..	2	2	8	11	12	8	7	2	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	52	31·74±·15	1·65±·10	5·20±·34
H. 4 (150) F_2	..	..	..	..	..	2	3	4	10	8	8	3	3	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	41	32·71±·17	1·74±·12	5·30±·39
H. 3 (171) F_2	..	..	..	..	..	..	..	4	10	11	18	6	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	49	33·24±·11	1·12±·08	3·37±·23
H. 7 (92) F_2	..	..	..	..	..	..	..	..	7	7	10	10	5	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	39	33·97±·12	1·26±·10	3·71±·28
H. 10 (140) F_2	..	..	..	..	..	..	..	..	..	..	2	3	4	8	10	2	2	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	31	27·13±·18	1·49±·12	4·01±·34
H. 1 (124) F_2	..	..	..	..	..	..	..	..	..	..	..	4	5	8	5	7	7	7	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	43	38·28±·19	1·88±·13	4·91±·35
H. 6 (142) F_2	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	2	3	3	4	3	2	2	1	..	..	..	..	..	..	..	..	..	20	43·10±·29	1·05±·19	4·52±·46

TABLE IV.

Frequency distribution of breadth index of leaves in a cross between Type 28 and Adcock.

No.	Breadth index classes																							Total No. of plants	Mean	Standard deviation	Co-efficient of variation
	18	21	24	27	30	33	36	39	42	45	48	51	54	57	60	63	66	69	72	75	78	81					
Adcock Parent	..	..	..	..	..	..	..	..	7	13	22	17	..	..	..	..	..	..	..	..	..	..	..	59	47·49±·25	2·89±·17	6·09±·38
Type 28 Parent	..	..	..	..	..	..	..	2	4	12	20	11	10	1	..	..	..	..	..	..	..	..	..	60	48·39±·34	3·97±·24	8·20±·50
Type 28 × Adcock F_1	..	..	..	..	..	..	..	..	4	9	24	14	1	..	..	..	..	..	..	..	..	..	..	52	47·94±·25	2·68±·18	5·59±·36
Type 28 × Adcock F_2	..	..	..	..	..	3	14	18	37	57	51	65	83	76	51	24	8	7	..	..	..	..	..	494	51·78±·22	7·40±·15	14·30±·29
Type 28 × Adcock H. 1 (124) F_3	3	17	25	3	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	48	23·74±·20	2·08±·14	8·76±·59
H. 4 (150) F_3	..	..	..	..	..	..	3	15	16	8	..	..	..	..	..	..	..	..	..	..	..	..	..	42	41·07±·31	3·37±·22	7·08±·46
H. 2 (164) F_3	..	..	..	..	..	..	..	1	4	15	18	9	5	..	..	..	..	..	..	..	..	..	..	52	47·61±·31	3·37±·22	7·08±·46
H. 3 (171) F_3	..	..	..	..	..	..	..	..	3	6	8	19	9	5	..	..	..	..	..	..	..	..	..	50	50·40±·37	3·90±·26	7·74±·52
H. 10 (140) F_3	..	..	..	..	..	..	..	..	..	..	1	2	3	12	6	4	3	..	..	..	..	..	..	31	56·26±·50	4·22±·36	7·24±·61
H. 8 (177) F_3	..	..	..	..	..	..	..	..	..	..	..	3	7	9	11	11	4	1	..	..	..	..	..	46	59·34±·43	4·37±·30	7·36±·51
H. 6 (142) F_3	..	..	..	..	..	..	..	..	..	..	..	1	5	9	4	1	..	..	..	..	..	..	..	20	56·85±·40	2·72±·27	4·79±·51
H. 7 (92) F_3	..	..	..	..	..	..	..	..	..	..	..	..	4	5	8	8	8	6	2	..	..	..	..	41	62·70±·50	4·98±·37	7·94±·59
H. 5 (102) F_3	..	..	..	..	..	..	..	..	..	..	..	..	..	2	6	9	10	8	6	5	5	1		52	67·89±·56	6·07±·40	8·94±·59
H. 9 (156) F_3	..	..	..	..	..	..	..	..	..	..	..	..	..	4	6	13	11	7	4	3	3	..		51	65·97±·52	5·51±·36	8·35±·55

Table I shows that of the two parent varieties in the cross "Adcock" was about ten days earlier than Type 28. In F_1 the mean of the flowering period was leaning towards the Adcock parent, that is, earliness was dominant. The mean of the flowering period of F_2 was smaller than that of the earlier parent, but the range of variation in F_2 was, however, greatly extended and the co-efficient of variation was nearly twice that of either parent.

In F_3 new types which were earlier and later than the parents were obtained. This shows that new genetic combinations have been produced.

Table II shows that of the two parent varieties in the cross Type 28 was taller than Adcock. In F_1 the mean height was much greater than that of the taller parent, that is, tallness was dominant. F_2 exhibited a mean height a little lower than F_1 but much higher than that of either parent. The range of variation in height was greatly extended and exceeded the combined range of both the parents. The co-efficient of variation was more than twice that of either parent. In F_3 types beyond the parental extremes were obtained.

From Table III it is clear that the two parental varieties in the cross show only a slight difierence in the number of leaves. In F_1 the mean leaf number was a little above that of the parent having the largest leaf number, that is, the larger number of leaves was dominant. The F_2 exhibited a mean leaf number much higher than that of the F_1 and of both the parents. The range of variation was greatly extended beyond the combined range of both the parents. The co-efficient of variation was more than twice that of either parent.

Table IV shows that the mean breadth index of the leaves of the two parent varieties and F_1 was practically the same. F_2 exhibited a mean breadth index which was higher than either parent. The range of variation was greatly extended and the co-efficient of variation was nearly twice that of either parent.

From the foregoing Tables it is clear that the F_2 generation was of great complexity, that the parental types did not reappear in F_2, and that new characters not present in either parent appeared in the offspring. This agrees with the results of the earlier workers Jensen [1907-1911] and Lodewijks [1911]. The appearance of plants with new characters in the progeny was most interesting, especially the appearance in F_2 of a variety with large absolutely white flowers, broad ovate leaves and a greater stature than either parent. As this variety has now been grown for three consecutive seasons and found constant from the first, it must have originated in homozygous condition. It does not appear to have been identified before.

The hybrids are now being tested for yield and quality.

V. Classification of the Hybrids.

1. Morphological Characters.

The chief morphological characters in which the hybrids differ are the plant habit, leaves, inflorescence and flowers :—

Habit. The differences in plant habit are generally caused by the length and number of internodes, by the arrangement of inflorescence and by the leaves and their angle of insertion on the stem.

Internodes of the various hybrids vary from 27 to 38 in number and from 4 to 7 cm. in length.

Leaves. The leaves of Hybrid 1 are lanceolate and those of Hybrids 2, 3 and 4 are elliptical but those of Hybrids 5, 6, 7, 8, 9 and 10 are broad ovate. The angles of insertion of the leaves vary from 60° to 90° in the various hybrids.

The leaf shapes of the parents, F_1 and the various hybrids are shown on Plate XLV.

Inflorescence of the hybrids is either compact or well open and inconspicuous or much raised above the leaves.

Flower. Excepting the corolla, there are not many differences in the flowers of the various hybrids.

Calyx. The relative lengths of the calyx and corolla do not vary much in different hybrids ; the calyx is about $\frac{1}{3}$ the length of the corolla practically in all the cases.

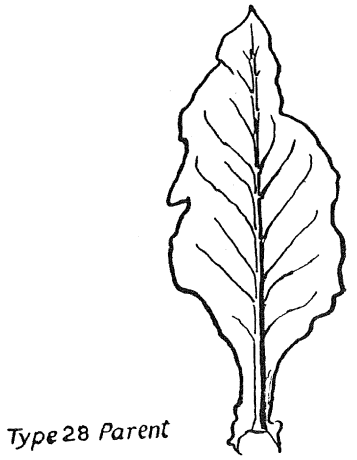
Corolla. The orifice varies from 7 to 12 mm., the transition between the tube and the dilated portion is either gradual or abrupt, the lobes are either deeply divided or practically not divided at all and the corolla appears as ball shaped, the corolla colour generally varies among various shades of pink excepting in the case of Hybrid 9, which has absolutely white flowers.

Capsule. The capsules of nearly all the hybrids are generally conical.

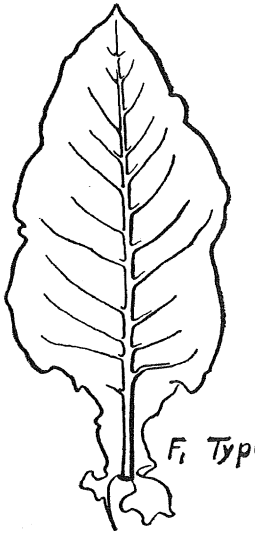
Considering all the various characters in which the hybrids differ, the leaf shape is considered to be the best for the main divisions in the classification and the plant habit for further sub-divisions.

2. Key to the Classification.

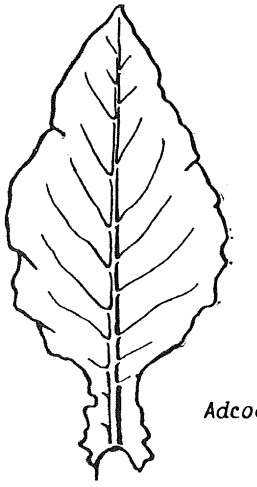
Leaves lanceolate
  Internodes short
    Inflorescence open and much raised . . . . . H. 1 (124)
Leaves elliptical
  Internodes short
    Inflorescence rather compact and not much raised
      Plants early . . . . . H. 2 (164)



Type 28 Parent

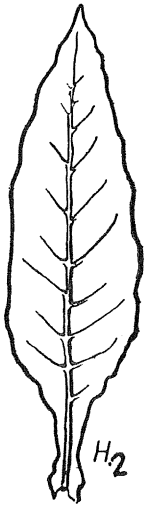


F1 Type 28 × Adcock

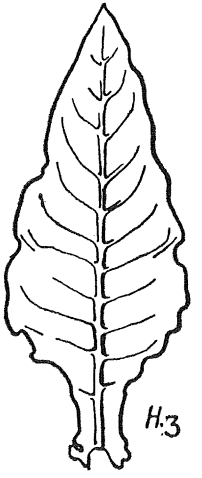


Adcock Parent

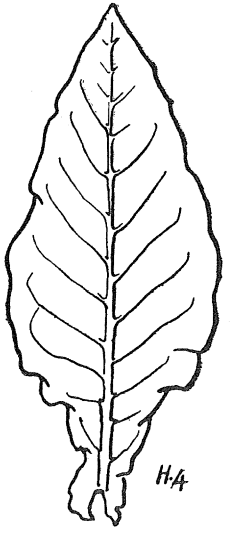
H.1



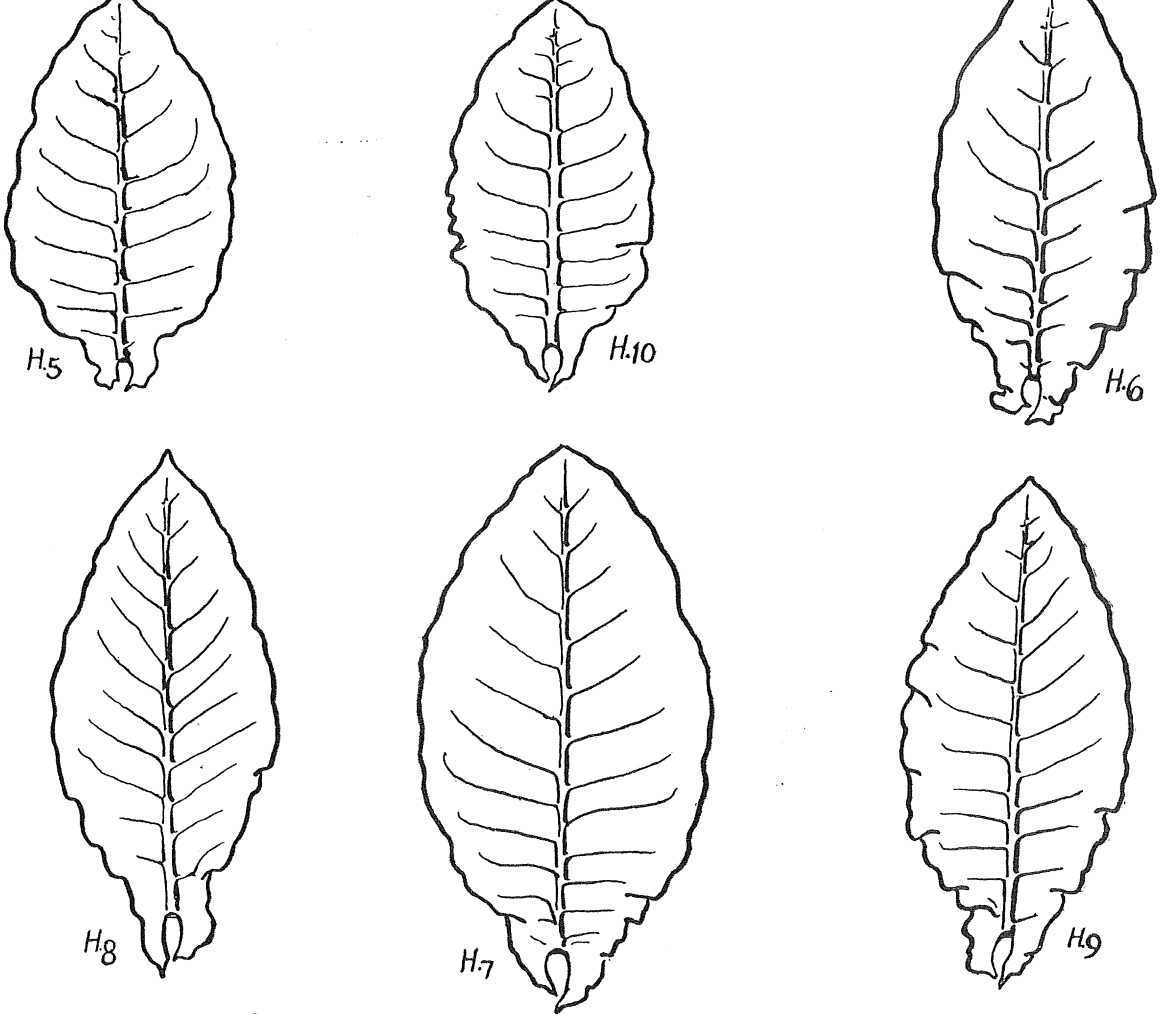
H.2



H.3



H.4



TYPICAL LEAF FORMS OF THE PARENTS, F_1 AND THE HYBRIDS.

Plants late . . . . . H. 3 (171)
Inflorescence rather compact but well raised . . . H. 4 (150)
Leaves ovate
Internodes medium
Inflorescence compact and somewhat raised . . . H. 5 (102)
Inflorescence compact and not much raised
Plants early . . . . . H. 6 (142)
Plants late . . . . . H. 7 (92)
Internodes long
Inflorescence open and well raised . . . . . H. 8 (177)
Inflorescence open but not much raised
Plants early, flowers white . . . . . H. 9 (156)
Inflorescence rather compact and not much raised . . H. 10 (140)

N.B.—The hybrids are numbered H. 1, H. 2, etc. The numbers in brackets are those under which the various hybrids are referred to in previous annual reports.

VI. Description of Selected Hybrids.

Hybrid 1. Plants somewhat late, tall; average height 199 cm.; internodes short below and long above, consequently most of the leaves are borne upon the lower half of the stem. *Leaves* sessile, inserted at an angle of 60°, slightly amplexicaul, decurrent, decurrency very narrow; lanceolate, lamina narrowed at about 15 cm. from the base and bent downward at a point about $\frac{1}{3}$ from the apex and folded on midrib; secondary veins arise at an angle of 45°; apex acuminate; margin undulate with big undulations and folds; surface rough and much raised between the secondary veins; colour dark green; texture thick; average length 60 cm.; ratio length/breadth 4·3. *Inflorescence leaves*, lanceolate and linear. *Inflorescence* open and much raised on long slender branches which grow as tall as the main axis. *Flowers* rather bent, light pink, fading to a lighter shade. *Calyx* tubular, about $\frac{1}{3}$ the length of the corolla; teeth very long and pointed. *Corolla* with an orifice of about 7 mm. in diameter; tube narrow; the transition between the tube and the dilated portion gradual; limb deeply divided; lobes triangular shaped at the base; apical points very long. *Capsule* about $\frac{2}{3}$ covered with the persistent calyx, conical; apex pointed.

Anthers burst after the flower opens and are below the stigma. In the fully open flowers the stigma projects beyond the orifice and the anthers are just opposite the orifice.

Hybrid 2. Plants rather early, medium in height, average height 140 cm.; internodes short, most of the leaves borne closely on the stem. *Leaves* sessile,

inserted at an angle of 60°, amplexicaul, and auriculate, decurrent, decurrency narrow : elliptical, lamina narrowed at about 15 cm. from the base and bent at about $\frac{1}{3}$ from the apex ; secondary veins arise at an angle of 60° and are fairly close : apex acute ; margin wavy ; surface slightly raised ; colour light green ; texture medium ; average length 50 cm. ; ratio length/breadth 2·0. *Inflorescence leaves* lanceolate. *Inflorescence* rather compact and not much raised, some of the side branches grow as tall as the main axis. *Flowers* pink, fading to a lighter shade. *Calyx* inflated and tubular less than $\frac{1}{3}$ the length of the corolla ; teeth long and pointed. *Corolla* with an orifice of about 7 mm. in diameter ; tube narrow ; the transition between the tube and the dilated portion gradual ; limb deeply divided with folds at the junction of the lobes ; lobes rounded at the base ; apical points long. *Capsule* almost covered with the persistent calyx, teeth of calyx projecting beyond the capsule, conical ; apex blunt.

The anthers burst before the flower opens and they are practically level with the stigma. In the fully open flowers the anthers and the stigma are just opposite the orifice.

Hybrid 3. Plants rather late, medium in height ; average height 155 cm. ; internodes short, leaves borne at an equal distance on the stem. *Leaves* sessile, inserted at an angle of about 75°, amplexicaul, decurrent, decurrency somewhat broad ; elliptical ; lamina narrowed at about 12 cm. from the base and slightly folded on midrib ; secondary veins arise at an angle of 75°, and are fairly close ; apex acute ; margin wavy with occasional large undulations especially towards the base ; surface rough, slightly raised between the secondary veins ; colour dark green ; texture thick ; average length 50 cm. ; ratio length/breadth 2·0. *Inflorescence leaves* elliptical to lanceolate. *Inflorescence* rather compact and not much raised, most of the secondary branches grow as tall as the main axis. *Flowers* deep pink, fading to lighter shade. *Calyx* inflated and tubular, about $\frac{1}{3}$ the length of the corolla ; teeth long and pointed. *Corolla* with an orifice of about 7 mm. in diameter ; tube narrow ; the transition between the tube and the dilated portion gradual ; limb slightly divided and recurved with slight folds at the junction of the lobes, lobes somewhat rounded at the base ; apical points short. *Capsule* about $\frac{2}{3}$ covered with the persistent calyx, conical ; apex pointed.

The anthers burst before the flower opens. In most of the fully open flowers the stigma projects beyond the anthers and reach the orifice but the anthers remain much below the orifice.

Hybrid 4. Plants early, medium in height ; average height 160 cm., lower, internodes short, upper medium, leaves closely borne on the stem. *Leaves* sessile, inserted at an angle of 60°, amplexicaul and decurrent, decurrency broad ; elliptical ; lamina narrowed at about 15 cm. from the base and slightly bent from about the

middle towards the ground, secondary veins arise at an angle of 60° ; apex acuminate ; margin undulate and recurved ; surface quite smooth ; colour light green ; texture thin ; average length 80 cm. ; ratio length/breadth 2·5. *Inflorescence leaves* lanceolate. *Inflorescence* rather compact but well raised, secondary branches grow as tall as the main axis. *Flowers* deep pink, fading to a lighter pink. *Calyx* somewhat globular, inflated, less than $\frac{1}{3}$ the length of the corolla ; teeth long and pointed. *Corolla* with an orifice of 9 mm., in diameter ; tube broad ; the transition between the tube and the dilated portion somewhat gradual ; limb practically undivided with folds at the junction of the lobes ; lobes broad and triangular shaped at the base ; apical points medium and twisted. *Capsule* about $\frac{2}{3}$ covered with the persistent calyx, conical ; apex somewhat pointed.

The anthers burst before the flower opens and they are practically level with the stigma. In the fully open flowers only the stigma reaches the orifice and the anthers remain a little below the orifice.

Hybrid 5. Plants early, medium in height ; average height 146 cm. ; internodes medium ; leaves distributed at an equal distance on the stem. *Leaves* sessile inserted at an angle of about 75°, amplexicaul and decurrent, decurrency broad ; ovate, lamina narrowed very near the base ; secondary veins arise at an angle of 75° and they are far apart ; apex acute ; margin undulate and recurved, colour light green ; texture medium ; average length 44 cm. ; ratio length/breadth 1·5. *Inflorescence leaves* are similar to the lower leaves but smaller in size. *Inflorescence* rather compact and somewhat raised, the secondary branches grow as tall as the main axis. *Flowers* pink, fading to a lighter shade. *Calyx* globular, inflated, about $\frac{1}{3}$ the length of the corolla ; teeth short and pointed. *Corolla* with an orifice of about 7 mm. in diameter ; tube broad ; the transition between the tube and the dilated portion abrupt, limb slightly divided with slight folds at the junction of the lobes ; lobes somewhat triangular shaped at the base ; apical points short. *Capsule* about $\frac{2}{3}$ covered with the persistent calyx, conical ; apex somewhat blunt.

The anthers burst before the flower opens and they are level with the stigma. In the fully open flowers the anthers and the stigma remain just below the orifice.

Hybrid 6. Plants tall, early ; average height 185 cm. ; internodes medium, leaves distributed at an equal distance on the stem. *Leaves* sessile, inserted at an angle of 75°, amplexicaul and decurrent, decurrency broad ; ovate, lamina narrowed very near the base and twisted to one side ; secondary veins arise at an angle of 75° and they are far apart ; apex acute ; margin undulate and much recurved with one or two big folds about the middle of the leaf ; surface smooth ; colour light green ; texture thin ; average length 45 cm. ; ratio length/breadth 1·6. *Inflorescence leaves* elliptical. *Inflorescence* rather compact and not much raised, secondary branches grow as tall as the main axis. *Flowers* pink, fading to a lighter shade. *Calyx*

globular, inflated, less than $\frac{1}{3}$ the length of the corolla ; teeth short and pointed. *Corolla* with an orifice of 9 mm. in diameter ; tube broad ; the transition between the tube and the dilated portion abrupt ; limb practically undivided, with slight folds at the junction of the lobes ; lobes slightly rounded at the base ; apical points very short. *Capsule* about $\frac{3}{4}$ covered with persistent calyx, conical ; apex somewhat pointed.

The anthers burst before the flower opens and are practically level with the stigma. In the fully open flowers the anthers and stigma are a little below the orifice.

Hybrid 7. Plants very late, tall ; average height 182 cm.; internodes medium. *Leaves* sessile, inserted at an angle of about 60°, amplexicaul and decurrent, decurrency broad ; ovate, lamina narrowed very near the base ; secondary veins arise at an angle of 75°, and they are far apart ; apex obtuse ; margin wavy ; surface somewhat smooth ; colour dark green ; texture thick ; average length 58 cm.; ratio length/breadth 1·6. *Inflorescence leaves* elliptical. *Inflorescence* rather compact and not much raised, the secondary branches remain below the main axis. *Flowers* light pink, fading to still lighter shade. *Calyx* globular, inflated, about $\frac{1}{3}$ the length of the corolla ; teeth short and pointed. *Corolla* with an orifice of 12 mm. in diameter ; tube broad ; the transition between the tube and the dilated portion abrupt ; limb slightly divided with folds at the junction of the lobes ; lobes much rounded at the base ; apical points short. *Capsule* about $\frac{3}{4}$ covered with the persistent calyx, conical ; apex blunt.

The anthers burst before the flower opens and they are level with the stigma. In the fully open flowers the anthers and stigma remain much below the orifice.

Hybrid 8. Plants early, tall ; average height 189 cm.; internodes long ; leaves borne at an equal distance on the stem. *Leaves* sessile, inserted at an angle of about 75° amplexicaul, decurrent, decurrency fairly broad ; elliptical lamina narrowed at about 15 cm. from the base and drooping downward from about the middle ; secondary veins arise at an angle of 60° and these are far apart ; apex acute ; margin undulate ; surface slightly raised between the veins ; colour somewhat light green ; texture thick ; average length 60 cm., ratio length/breadth 2·0. *Inflorescence leaves* similar to the lower leaves but smaller in size. *Inflorescence* open and well raised, the secondary branches grow as tall as the main axis. *Flowers* light pink fading to still lighter pink. *Calyx* loose and baggy, about $\frac{1}{3}$ the length of the corolla ; teeth medium and pointed. *Corolla* with an orifice of 12 mm. in diameter ; tube broad ; the transition between the tube and the dilated portion somewhat gradual ; limb undivided with slight folds at the junction of the lobes ; lobes triangular shaped at the base ; apical points short. *Capsule* almost covered with the persistent calyx, conical ; apex pointed.

The anthers burst before the flower opens and they are level with the stigma. In the fully open flowers the anthers and stigma remain a little below the orifice.

Hybrid 9. Plants early, tall; average height 195 cm.; internodes long, leaves distributed at an equal distance on the stem. *Leaves* sessile, inserted at an angle of 75°, amplexicaul, decurrent, decurrency broad, ovate; lamina narrowed at about 10 cm. from the base and bent downward at a point $\frac{1}{3}$ from the apex; secondary veins arise at an angle of about 90° and they are far apart; apex acute; margin wavy and recurved with occasional big undulations which are more frequent in the middle; surface slightly raised between the veins colour light green; texture medium; average length 60 cm., ratio length/breadth 1·5. *Inflorescence leaves* somewhat elliptical. *Inflorescence* fairly open and not much raised, the side branches grow as tall as the main axis. *Flowers* big pure white. *Calyx* loose and baggy about $\frac{1}{3}$ the length of the corolla; teeth short and pointed. *Corolla* with an orifice of 12 mm. in diameter; tube broad; the transition between the tube and the dilated portion abrupt; limb practically undivided with slight folds at the junction of the lobes; apical points short. *Capsule* almost covered with the persistent calyx, conical; apex pointed.

The anthers burst before the flower opens and they are level with the stigma. In the fully open flowers the anthers and stigma remain a little below the orifice.

Hybrid 10. Plants late, tall; average height 195 cm., internodes long, leaves distributed at an equal distance on the stem. *Leaves* sessile, inserted at an angle of about 60°, amplexicaul, decurrent, decurrency broad and extends down to the base of the leaf immediately below; ovate; lamina narrowed very near the base and twisted to one side; secondary veins arise at an angle of more than 75° and they are fairly far apart; apex acute; margin undulate and recurved; surface somewhat raised between the secondary veins; colour light green; texture medium; average length 45 cm.; ratio length/breadth 1·5. *Inflorescence leaves* are similar to the lower leaves but smaller in size. *Inflorescence* rather compact not much raised, the side branches grow as tall as the main axis. *Flowers* pink fading to lighter pink. *Calyx* loose and baggy, less than $\frac{1}{3}$ the length of the corolla; teeth short and pointed. *Corolla* with an orifice of 9 mm. in diameter; tube broad; the transition between the tube and the dilated portion abrupt; limb divided with slight folds at the junction of the lobes; lobes rounded at the base; apical points medium and pointed. *Capsule* about $\frac{2}{3}$ covered with the persistent calyx, conical; apex blunt.

The anthers burst before the flower opens and they are practically level with the stigma. In the fully open flowers the anthers and stigma are just opposite the orifice.

VII. Summary.

The tobacco crop sown as early as 15th July in Bihar grows well but it is susceptible to "leaf spot" and "Curly disease", whereas a crop sown later than

the first week of August does not suffer so heavily from these diseases but gives a somewhat smaller yield of leaf. These differences are more pronounced when the tobacco is an imported exotic variety such as Adcock. The indigenous types of Indian tobacco are hardy and heavy yielders but none are good in quality for cigarette manufacture.

In order to produce a variety of tobacco which while retaining the hardy growing characters of an indigenous type may also be better in quality from the point of view of cigarette manufacture, the local type 28 was crossed with Adcock.

In general vigour the F_1 plants were intermediate between the two parents and neither was completely dominant over the other.

In F_2 the range of variation was greatly extended and the co-efficient of variation was more than twice that of either parent. The F_2 generation was of great complexity, the true parental types did not reappear in F_2 and new characters not present in either parent appeared. The appearance in F_2 of a variety with large absolutely white flowers was very interesting as the flower colour of both the parents used in the cross was pink.

The ten newly-produced hybrids have been obtained in a homozygous condition and are now breeding true. These hybrids are now being tested for their leaf quality both by ground curing and flue-curing methods. The preliminary test with one hybrid 8 (177) has given encouraging results.

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SOME OBSERVATIONS ON BAMBOOS.

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(With Plates XLIX to LIII and one text-figure.)

1. FLOWERING IN BAMBOOS.

Flowering in bamboos is rare, and occurs only at intervals of many years, different varieties behaving differently. According to Brandis bamboos are divided into three classes with regard to their flowering; (1) those that seed yearly and die after the seed is ripe; (2) those that flower profusely and at long intervals, all culms of one clump or all clumps in one district flowering simultaneously; (3) those that flower irregularly. Definite data with regard to the flowering of these three classes is not available. B. Tulda and B. Balcooa Watt, the two varieties commonly met with in districts of Bengal and Behar, seem to belong to the second class of Brandis. In March 1930, a few clumps at different places in the Pusa estate flowered and set seed. It was observed that before the onset of flowering the plants had quite a green foliage which, however, fell off as the ripening of the seed proceeded, the plants being left destitute of any leaves. It was also interesting to note that the clumps flowering at the same time were not of the same age.

TABLE I.

No. of clumps that flowered	Age record	Method by which the plants were propagated
1. 2 .	More than 100 years old . .	Not known.
2. 2 .	14 years	Cuttings from the first clump No. 1.
3. 1 .	6 years old	Cuttings from No. 2.

Thus it appears that the duration of life of the plants in every species is perfectly fixed and is renewed only by seed and it is immaterial whether cuttings are

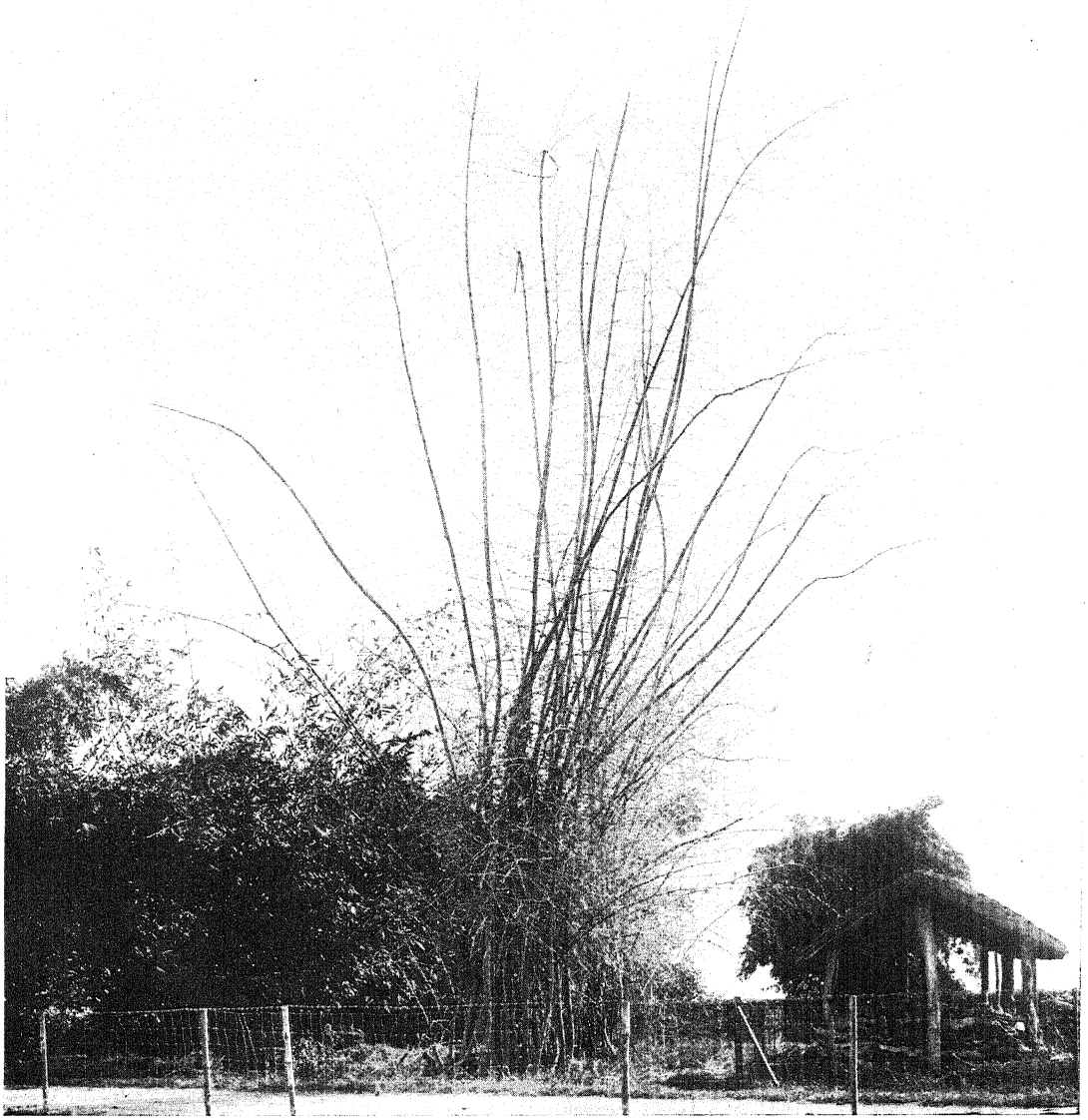
taken a few years or many years before flowering, the parent or stock plant as well as the plants raised from cuttings all flower and die at the same time, the mother plants however bear and seed more profusely than the daughter ones. The six-years old plants were found to give very few seeds and most of the branches did not even produce flowers. They, however, died with the rest. Just after the seeds are properly ripened, they begin falling from the spikelets and the bamboo plants put on a brown mature look instead of the living green and take 2-3 months to dry up completely (Plate XLIX). Rarely the underground rhizomes begin throwing out new shoots, if favourable conditions with regard to moisture are obtained. They, however, never grow into shoots of economic importance, because very early in their life they begin to flower and dry up like the mother plant from which they take their origin. In one case it was observed that the new shoots began flowering a week after their emergence. This fact confirms the view that rejuvenation in bamboos is only possible by sowing it from seed.

2. Bamboo Seeds.

It is a common belief that the bamboos even when they flower do not always produce viable seed. Many of the Japanese species have never been known to form mature seed [Fairchild, 1903] but at Pusa, as elsewhere in India, the flowering clumps produced plenty of viable seed.

The seed of bamboo when freed of its kernels resembles that of wheat and measures 5 to 8 mm. long and 2·5 mm. broad. Strictly speaking, it is not a seed but a fruit (caryopsis) for there is only one seed in the ovary and the walls are fused with those of the fruit to an indistinguishable degree. The embryonic plant lies obliquely across one end of the seed, the rest being taken up by the starch containing cells, the endosperm. This serves as food during the early stages of development. Due to the rare phenomenon of flowering the bamboo seeds are possessed of very high powers of germination and keep viable over long periods, though the greatest percentage of germinations is only obtained by sowing the seed just after it is mature.

The early developmental stages are similar to those of other grass seeds. The radicle is the first to make its appearance. The plumule takes a little longer and may take 2 to 3 days to clear itself of its seed-coat and increase in length before it unfolds its first leaf. In the soil it takes about 9 to 12 days to become visible on the surface and the first leaf is observed a few days after its first appearance above-ground. The seed-coat remains attached to the plant for a considerable length of time and its presence is of very great help in detecting the mother shoot later on when other shoots have come up.



A BAMBOO PLANT AFTER FLOWERING.

3. Mode of underground branching.

In the bamboo seedlings it is noticed that the first incipient bud on the mother shoot becomes thickened and elongated and often takes a dip downwards, before sending out a shoot to reach the surface of the soil. This is the first attempt on the part of the plant to set about making a reserve to draw upon in times of need. Each node contains its own root-zone, which develops into the adventitious root-system to supply the increasing demands of the growing shoot. After this stage more and more shoots are added to the plant, each new shoot arising from the rhizome of the next higher order. The measurements of the height aboveground of the plant, its thickness and length of the joints were taken and it was found that each succeeding shoot excels the preceding one in height, thickness and length of the joint. (Table II).

Table II.

Showing the length and thickness of joints and height aboveground of shoots of different orders.

Order of shoot	Length of joints in mm. measured from below upwards										Thickness of middle joint mm.	Height of shoots above ground cms.
	1	2	3	4	5	6	7	8	9	10		
Shoots of 1st order (*a*) .	7	11	12	14	6	9	8	9	7	8	0·9	16·7
„ „ 2nd „ (*b*) .	20	21	24	30	44	46	46	50	43	..	2·5	30·0
„ „ 3rd „ (*c*) .	32	33	41	45	49	40	38	29	..	..	3·4	46·5
„ „ 4th „ (*d*) .	30	51	65	55	40	32	36	32	..	..	4·2	60·0
„ „ 5th „ (*e*) .	42	73	91	89	90	90	..	..	..	..	5·1	67·2
„ „ 6th „ (*f*) .	Just emerging				.	.	.	.	.	.	..	..

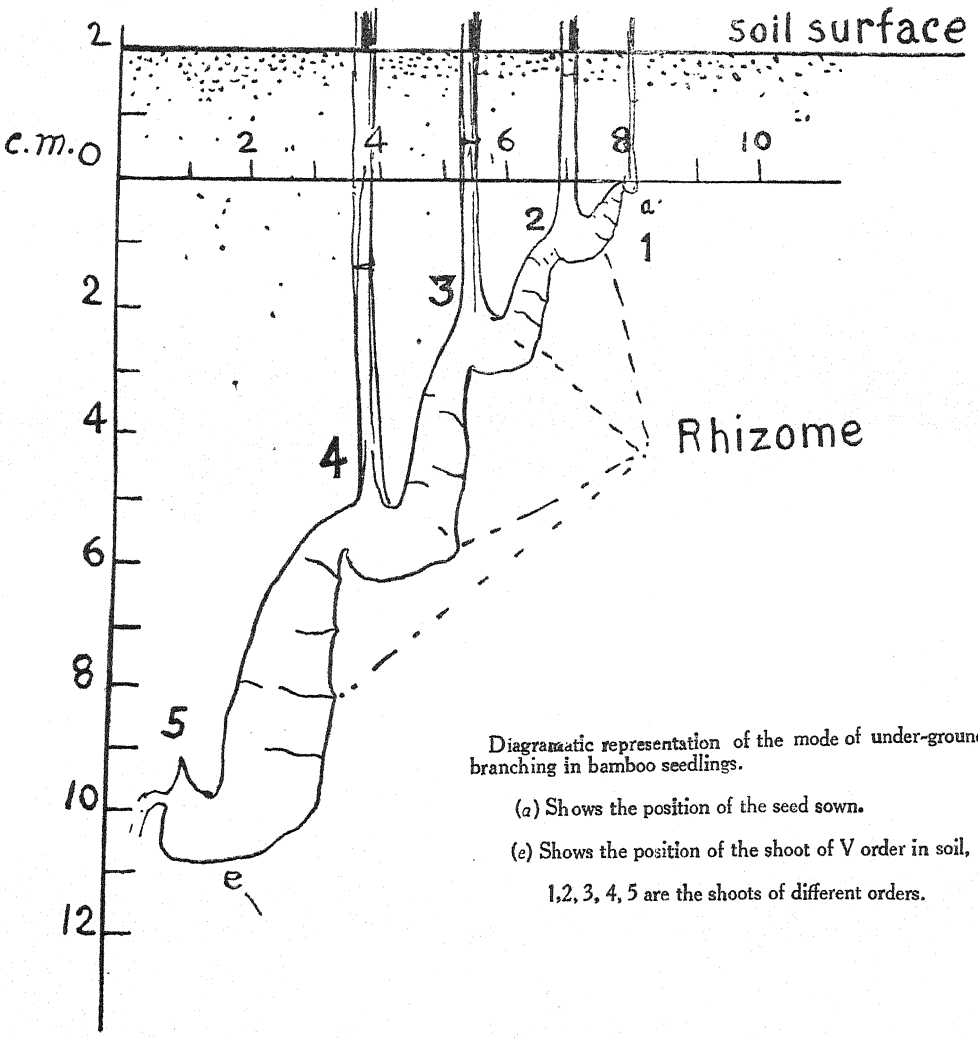
Note.—All figures are averages of 20 counts each.

Leaves are only 1·5×1·3 cm. in the case of the mother shoot but may measure as much as 7·2×1·8 cm. in the shoots of the fifth order. (Table III).

Table III.

Order of shoot	Leaf length cm.	Leaf breadth cm.	Remarks
Shoots of 1st order (*a*) . . .	1·6	1·2	
„ „ 2nd „ (*b*) . . .	2·8	1·5	
„ „ 3rd „ (*c*) . . .	4·4	1·7	
„ „ 4th „ (*d*) . . .	6·6	1·7	Average of 20 Counts.
„ „ 5th „ (*e*) . . .	7·2	1·8	

The more elaborate system of the food-manufacturing organs seems to be responsible for the greater thickness and greater height, etc., of the shoots of higher order. Another feature of the bamboo seedling is its development in one direction only. The shoots of the different orders are produced at ever increasing distances from the mother shoots. Each shoot gives out its own rhizome which becomes thicker and thicker as higher orders of shoots are reached. Each succeeding shoot arises from below the surface at a much greater depth than the original mother shoot (Fig. 1).



Diagramatic representation of the mode of under-ground branching in bamboo seedlings.

(*a*) Shows the position of the seed sown.

(*e*) Shows the position of the shoot of V order in soil,

1,2, 3, 4, 5 are the shoots of different orders.

Fig .1

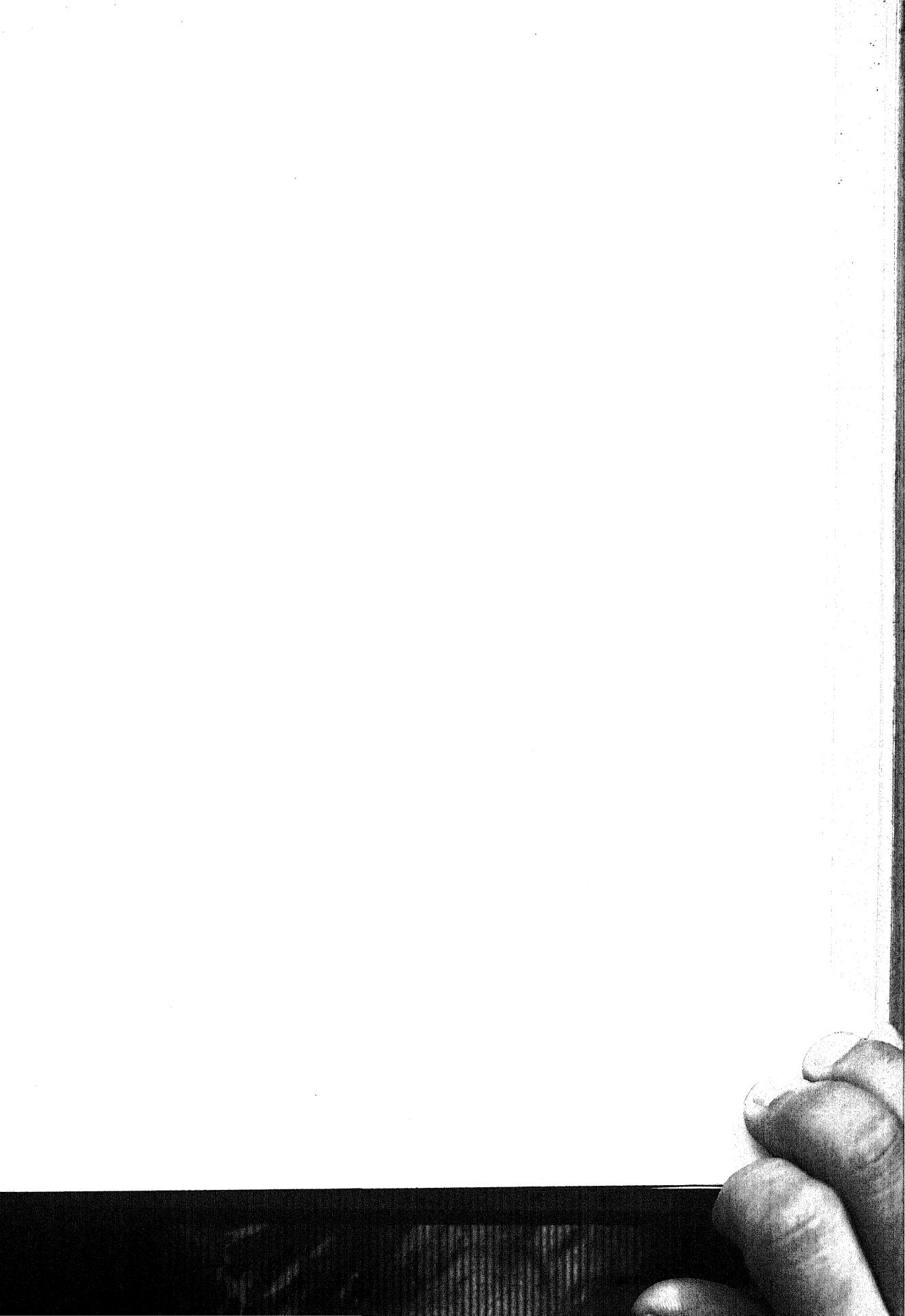
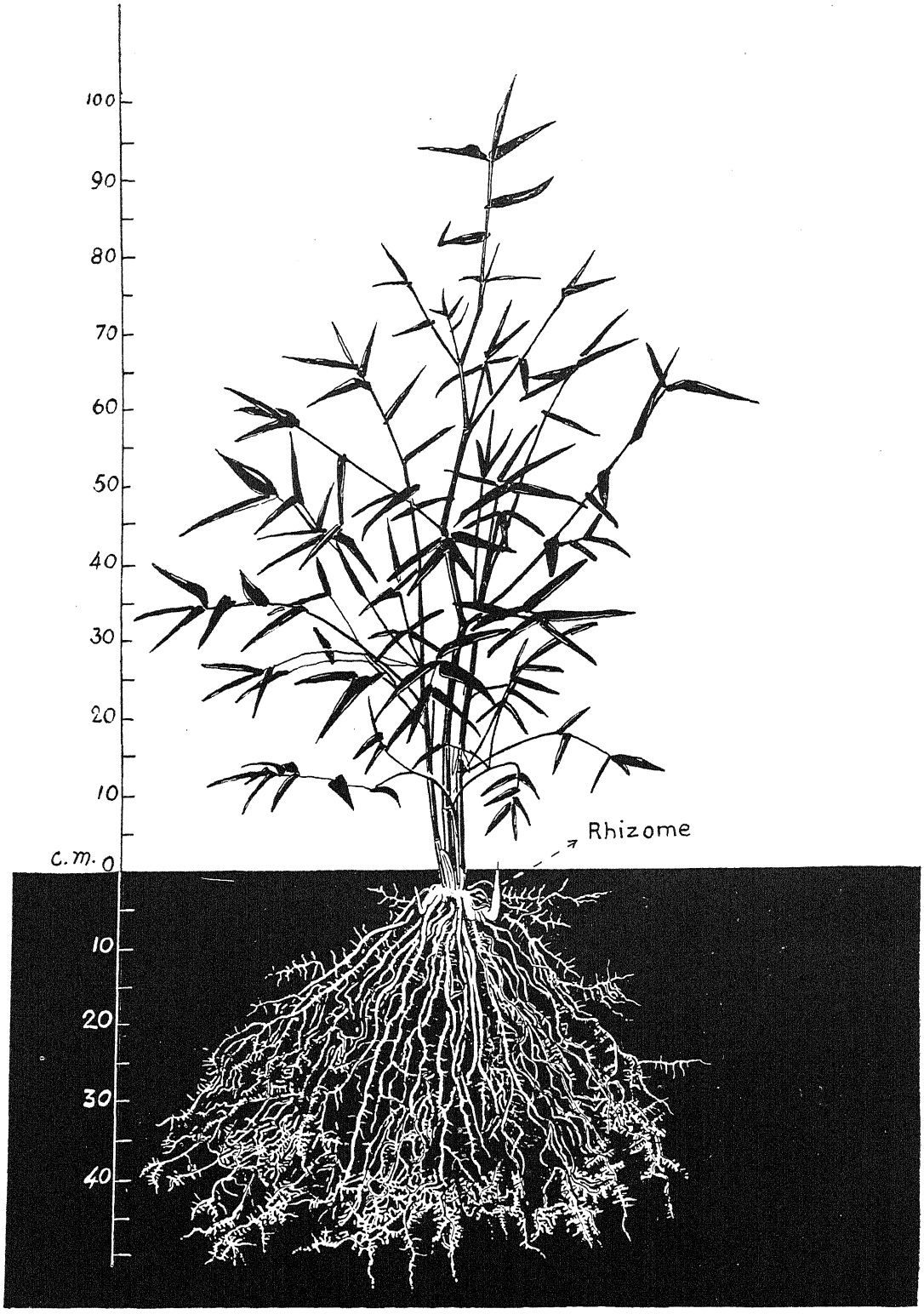


PLATE LI.



A BAMBOO SEEDLING 5 MONTHS OLD—EXHIBITING ITS ROOT-SYSTEM. THE BRANCHING JUST BELOW THE SURFACE LAYERS AND THAT AT ENDS IS CHARACTERISTICALLY MARKED.

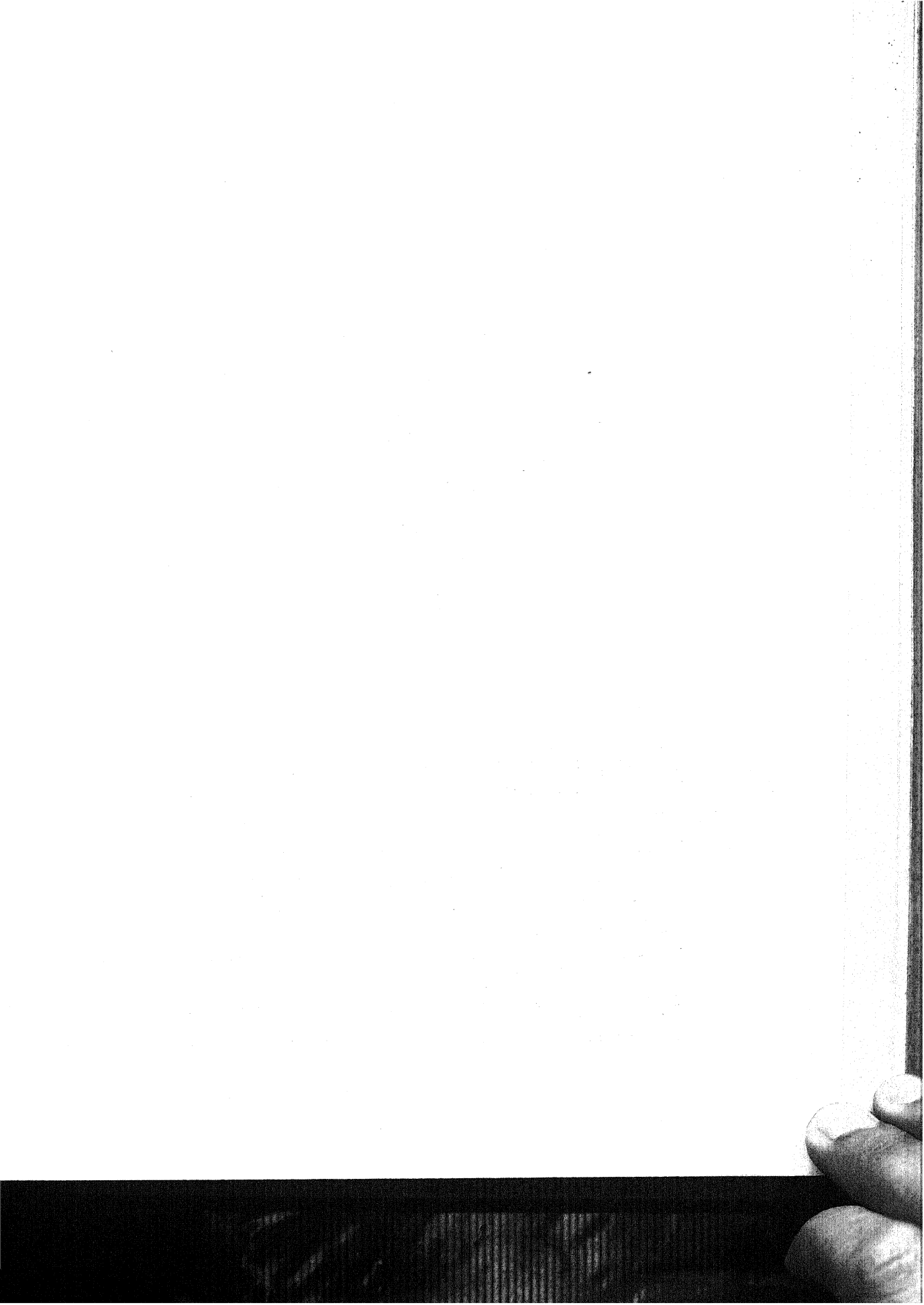
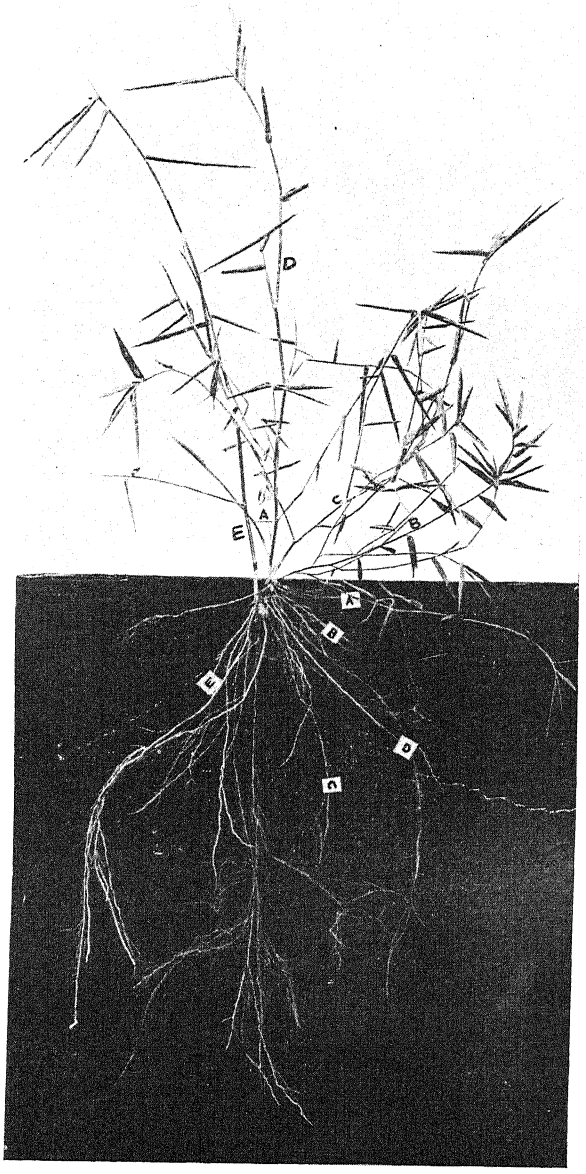


PLATE L.



A BAMBOO SEEDLING 5 MONTHS OLD.

(1) White back ground—shows the length and thickness of the joints and height above-ground of the shoot of different orders. A is the mother shoot or shoot of the 1st order ; B, C, D, and E are the shoots of the II, III, IV and V orders respectively.

(2) Black back ground—shows the roots labelled A, B, C, D, E, emanating from the shoots of I, II, III, IV and V order.

Note the increase in thickness of the roots in the shoots of higher order.

It was also observed that each shoot gets a check in growth after it has excelled the preceding shoot in height. The course of food seems to be diverted for some time to the development of the rhizome which develops very quickly and sends out a small pointed shoot above ground, before the preceding shoot has fully completed its height. When once the shoot has attained the soil surface it grows remarkably quickly and additions of 4 to 6 cm. in height per day are not uncommon. This growth rate is kept up till the shoot of next higher order is seen making its way to the surface when the growth rate falls and all energies are concentrated on the next shoot. It seems probable that this goes on till the shoot has attained the thickness representative of a particular variety under consideration.

4. Root-systems in Bamboos.

(*a*) *Seedlings.*—The root-system in bamboo seedlings is similar to that of sugarcane seedlings. The first-formed roots are short lived and dwindle into insignificance as soon as the shoot has formed its own roots. These roots too die after a time and are succeeded by those from the same shoot or one of a higher order. These roots as they take their origin from the shoots of different orders also share in the increases in size with the shoots (Plate L. and Table IV).

Table IV.

Order of shoots	Root thickness mm.	Remarks.
Shoots of 1st order (*a*)	0·5	
„ „ 2nd „ (*b*)	0·9	Average of 20 counts.
„ „ 3rd „ (*c*)	1·2	
„ „ 4th „ (*d*)	1·6	
„ „ 5th „ (*e*)	1·8	

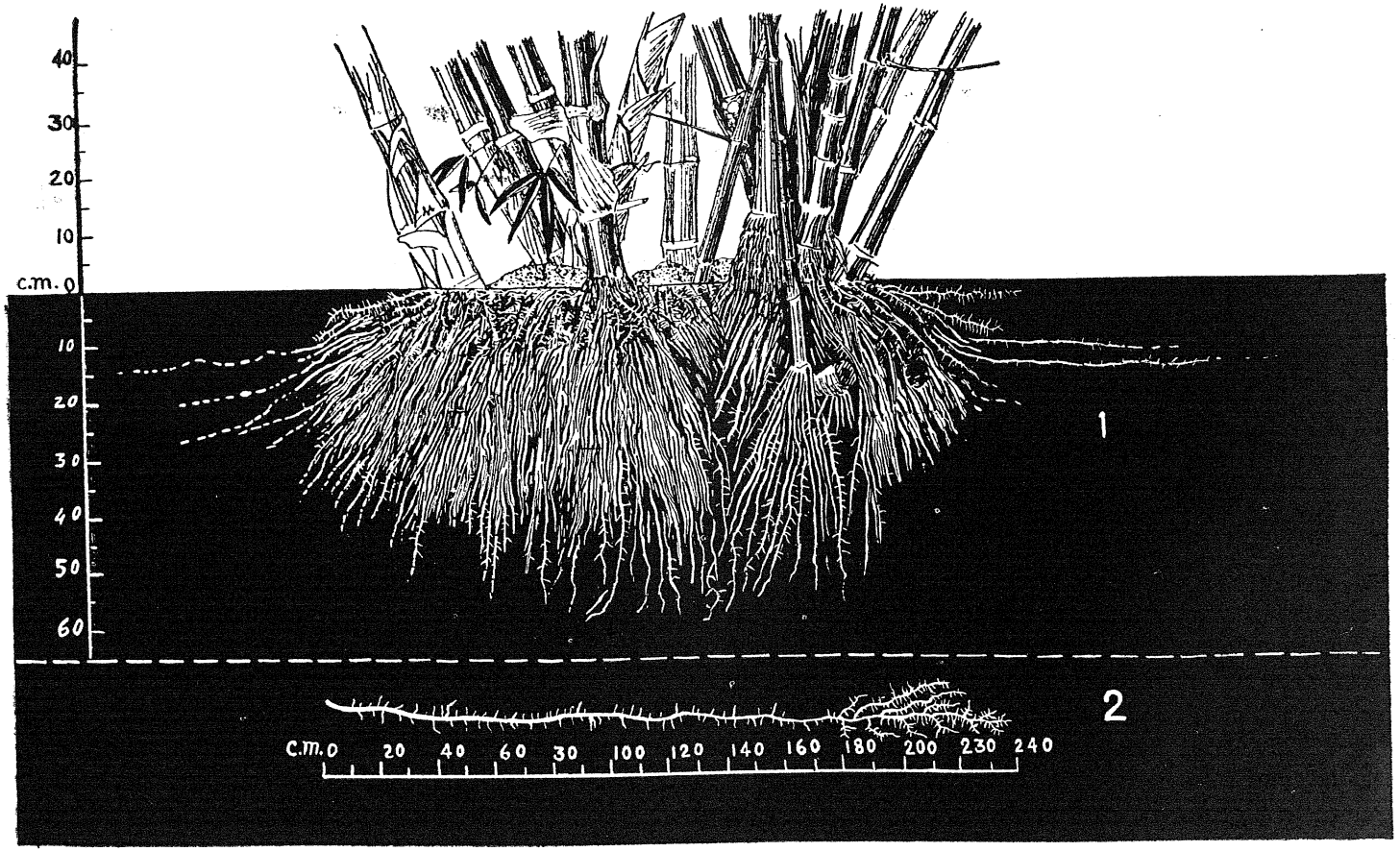
From the study of the mode of underground branching of shoots in bamboo seedlings it is evident that the roots emerging from the shoots of the higher orders are usually produced at deeper layers and that most of these roots spread superficially only. A few, however, do strike down to 50 cm. depth. The upper 20 cm. layer is characterised by very fine and slender branches and a network or matting at the ends is quite common. (Plate LI). The roots in general resemble those of sugarcane seedlings but differ from them in the duration of their functioning life. In sugarcane seedlings the first system of roots usually gets decayed after 28 to 42 days

depending upon the class of seedling, while in bamboo seedlings the first formed roots can be traced functioning even 4 months after the sowing of the seed. This may be attributed to the perennial nature of the bamboo plant.

(*b*) *Setts.*—The bamboo stock is made up of a series of joints separated from each other by the nodes and is usually hollow. The node is often of greater diameter than the internode and may be very much swollen in some cases. The length of joint or internode varies a good deal in the stalk of different seasons and increases from below upwards, the longest joints being met with somewhere about one-third to one-half the distance from the base of the stalk. At each node, and alternately on opposite sides, lies the eye or bud which is usually much flattened, pressed very close to the stalk and is most commonly ovate in shape and outline. It is covered over with persistent and coracious scales which shelter it from all sorts of unfavourable circumstances.

Along with the bud and in the same zone there, are a number of root primordia which are rather indistinct in the younger buds. In mature stalks, however, they swell up and given favourable conditions of moisture and darkness, they elongate and result in the temporary root-system of the plant. There is usually one row of these root primordia present, and this may contain as many as 72 of these dormant roots. All of these, however, do not become active and, in most cases, a good lot of them get injured in their swollen state. Thus, each node of the bamboo stalk is capable of giving rise to a new plant. The essential parts—the bud and the root eyes—are comparable to plumule and radicle of the seed but of course the sett possesses a greater reserve of plant food than the seed. The preliminary stages of root development are similar in both seed and sett plantings. Each newer flush of roots is thicker than its predecessors and possesses greater power of penetration. The greater thickness of the later-developed roots can be attributed to the greater amount of plant food these roots have at their disposal, [Venkataraman and Thomas, 1929].

The root-system of two-year old bamboo plants which have been propagated vegetatively, consists of a very heavy mass of whitish brown roots, 4 to 6 mm. in thickness (Plate LII). They branch rather meagrely and the depth of penetration is limited to 60 cm. below the soil surface. The lateral spread, however, is about 8 ft. all round though only the first five feet are profusely occupied. The spread seems to depend on the texture of soil. In soils of light nature and loose texture the spread exceeds that in the heavier class of soils. In plants growing near the river the roots are found to have occupied laterally greater distances than are usually taken up by the roots of plants in drier situation. The end portions of bamboo roots are characterised by masses of very fine and hair-like branchlets which insure the thorough tapping of the soil layers.



ROOT-SYSTEM OF TWO-YEAR OLD BAMBOO-PLANT (VEGETATIVELY PROPAGATED).

1. Vertical section through the soil showing the heavy mass of roots in the first 45 cms. layer from the soil surface. 2. A full-sized root branching at ends shown separately.

(*c*) *Old Plant.*—The root-system of a plant which had recently flowered was also studied and it was found that it did not differ much from that described above except for its greater depth of penetration which was 154 cm. from the surface of the soil (Plate LIII). There were also present a very large number of dead dark brown roots between 65 to 154 centimeter layers. No fresh roots were observed to be developing. From the presence of dead roots at different levels it appears that depth of penetration of the roots varies at different seasons in a year. During the rainy season most of the deep penetrating roots die off on account of the rise of the water-level and the plant during this period lives on the surface layer roots.

5. Rhizome—its Value in Bamboo Culture.

Very early in the life of a bamboo plant it evinces a strong desire to develop a rhizome to be used as a reserve of plant food. Each rhizome is bigger than the one preceding it (Fig. I), and is produced at greater depth. This seems essential from two points of view, firstly to enable the developing young shoot to outgrow in height its predecessors and to get as much light as possible ; and secondly to give a gregarious plant a strong hold in the soil which is necessary because the root-system of bamboo plant is limited to the surface layers only and does not go deep.

In bamboo culture the existence of the rhizome is of considerable importance because it ensures quick propagation owing to the large amount of easily assimilable food which the rhizome contains.

In the end, my grateful thanks are due to Dr. F. J. F. Shaw, the Imperial Economic Botanist, Pusa, for affording me facilities ; to Khan Sahib Abdur Rahman Khan, First Assistant to Imperial Economic Botanist, for placing at my disposal a large number of bamboo seeds and seedlings to carry on this study.

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THE INFLUENCE OF ALKALI SALTS ON NITRIFICATION IN SOME INDIAN SOILS.

BY

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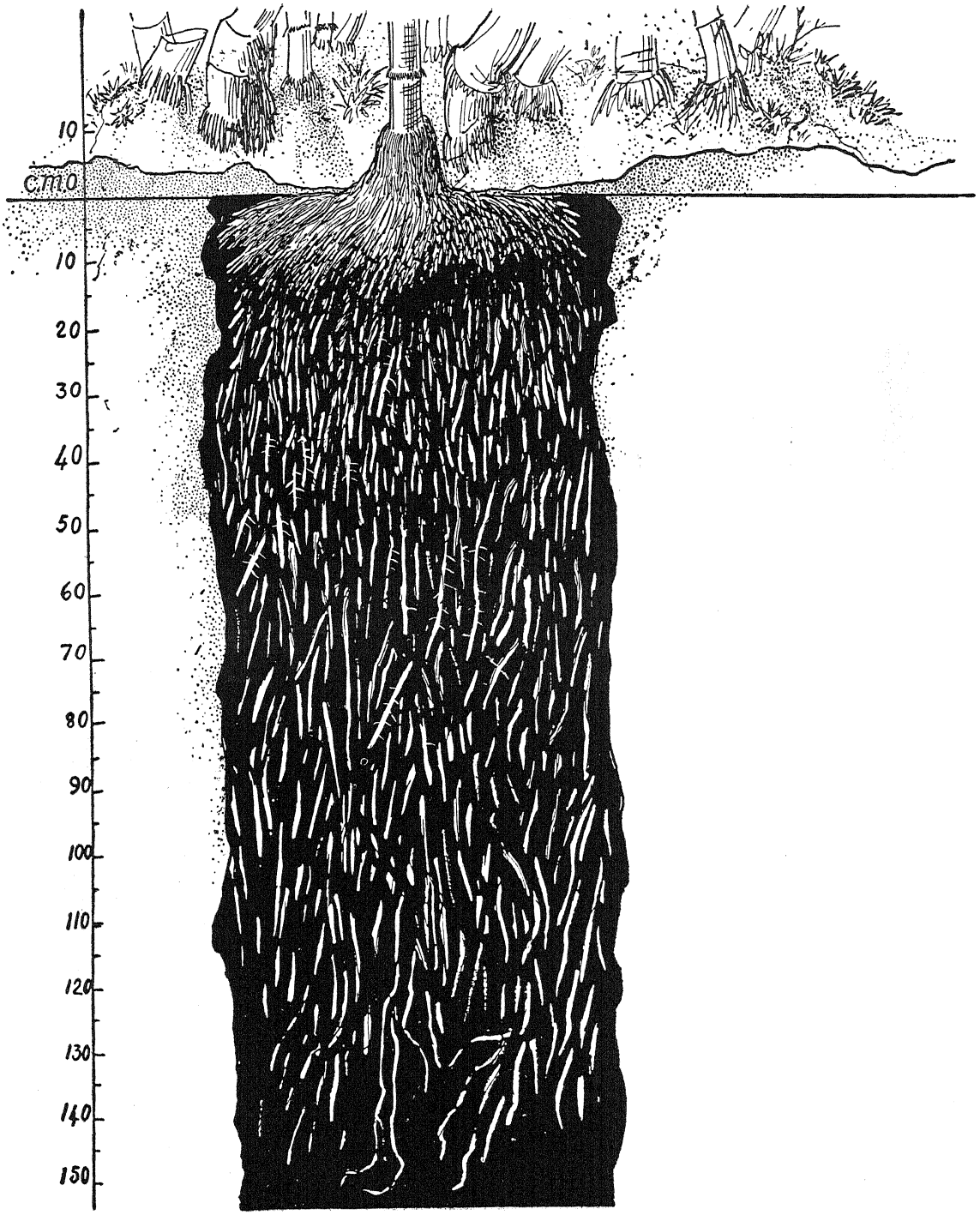
The influence on the nitrification processes in soil of carbonate, sulphate, and chloride of sodium, the presence of which gives rise to certain types of alkali soil to be found in India, has been studied by several workers in the United States. In most of their investigations the nitrification of only one type of nitrogenous manure in one type of soil has been studied by each worker, and the period of incubation has not exceeded four weeks. The results obtained have been by no means uniform, especially when sodium carbonate was added.

Lipman [1912] used light sandy soil from South California, fairly well supplied with humus. Two grams of dried blood were added to 100 grms. of soil, moisture content made up to 18 per cent. and incubation was for three weeks at 28° C. He found that ·05 per cent. of Na_2CO_3 was highly toxic, and on addition of 0·1 per cent. there was no production of nitrate.

Kelly [1916] used soil from the California Citrus Experiment Station, a light sandy loam, low in organic matter and nitrogen. Fifteen per cent. moisture was added and incubation was at 25°-28° C. for four weeks.

In the soil from control plots 0·05 per cent. Na_2CO_3 was toxic when 0·15 per cent. ammonium sulphate was added. 0·1 per cent. had small effect when 1 per cent. dried blood was added, and stimulated the nitrification of ·0625 per cent. ammonium sulphate.

In soil from manured plots, 0·05 per cent. Na_2CO_3 was toxic when 1 per cent. dried blood or 0·15 per cent. ammonium sulphate were added. On the nitrification of 0·1 per cent. dried blood, 0·4 per cent. sodium carbonate had little effect.



ROOT-SYSTEM OF A BAMBOO-PLANT (AFTER FLOWERING). SHOWING VERY FEW FUNCTIONING ROOTS ESPECIALLY IN DEEPER LAYERS.

Brown and Hitchcock [1917] used alkali soil from the University of Wyoming Agricultural Experiment Station. 100 mgms. ammonium sulphate were added to 100 grms. air dry soil, moisture made up to the optimum and 5 cc. of fresh soil infusion added to introduce a nitrifying flora; incubation was at room temperature for four weeks. Nitrification was stimulated by 0·05 per cent. Na_2CO_3, slightly stimulated by 0·1 per cent. and depressed by higher concentrations.

T. M. Singh [1918] used a heavy silt loam, from Oregon. 100 grms. soil was taken, the salt added, the soil brought to optimum moisture content, and incubated at room temperature for four weeks. The experiment was run in duplicate. Nitrification was stimulated by additions of sodium carbonate up to 0·5 per cent., was unaffected by 0·8 per cent. and slightly depressed by 1·0 per cent.

Greaves and his associates [1919] used soil from the College Farm, Utah, a very productive sandy loam. They give the complete physical and chemical analyses of the soil, which contains 0·15 per cent. N, 7·41 per cent. CaO, 4·15 per cent. MgO and 7·62 per cent. CO_2.

2 grms. dried blood were added to 100 grms. soil, moisture content 20 per cent., and incubation was at 28°—30° C. for 21 days. Sodium carbonate was toxic at the lowest concentration used, ·0016 per cent., but even at 0·32 per cent. was not so toxic as sodium chloride at 0·35 per cent.

When sodium sulphate was the added salt, Lipman [1912] found that 0·1 per cent. stimulated nitrification, 0·2 per cent. had no effect, 0·3 per cent. was toxic and 0·8 per cent. stopped nitrification altogether.

Kelly [1916] in soil from control plots found that 0·1 per cent. had slight effect on the nitrification of 0·1 per cent. and 0·5 per cent. dried blood or ·0625 per cent. ammonium sulphate, but was toxic to that of 0·15 per cent. ammonium sulphate.

In soil from manured plots 0·1 per cent. stimulated the nitrification of 1 per cent. dried blood, but had no effect with 0·1 per cent. dried blood or 0·15 per cent. ammonium sulphate. 0·5 per cent. was toxic with 1 per cent. dried blood or 0·15 per cent. ammonium sulphate, but showed no effect with 0·1 per cent. dried blood.

Brown and Hitchcock [1917] found that in normal soil it stimulated in quantities up to 2·072 per cent., but twice this quantity depressed nitrification considerably.

Singh [1918] found a stimulating effect with 0·2 per cent.; owing to the difference between his control duplicates, 89·2 and 50·8 mgms. nitrate per million parts soil, it is difficult to say what effect higher quantities had. With these higher quantities duplicates agreed well, and the mean with 0·4 per cent. was 86 mgms. and with 1 per cent. was 71 mgms. Even with 2 per cent. the depression of nitrification was only to 67·4 mgms.

Greaves [1919] found its effect to be about the same as that of sodium carbonate—toxic at all concentrations used.

Sodium chloride, 0·2 per cent., was generally found to be toxic. Lipman [1912] found that ·05 per cent. actively, and 0·1 per cent. slightly, stimulated nitrification. 0·2 per cent. was toxic and 0·4 per cent. stopped nitrification.

Brown and Hitchcock [1917] found that in normal soil ·005 per cent. stimulated, and over ·01 per cent. depressed nitrification.

Singh [1918] states that nitrification is checked by ·005 per cent., but the differences between duplicate determinations make this uncertain till the concentration of ·05 per cent. was reached.

Greaves [1919] found sodium chloride to be the only salt that increased nitrate accumulation, and was most active at a concentration of ·058 per cent., but toxic at ·23 per cent. and highly toxic at 0·35 per cent.

In our experiments nitrogen was added at the rate of 30 mgms. per 100 grms. soil, in the form of either sulphate of ammonia or mustard cake. The moisture was made up to the optimum for nitrification in each soil by the addition of distilled water in which the desired amount of the salt to be added was dissolved. Incubation was at 30° C., and loss of moisture was made up every week.

Samples weighing 50 grms. dry were withdrawn at intervals of one or more weeks, depending on the progress of nitrification in the particular soil, for eight weeks or more, and their nitrate, nitrite, and ammonia content determined.

Nitrates were determined colorimetrically by the phenol-di-sulphonic acid method, nitrites by the Griess-Ilosway method and ammonia by the Schloesing method.

The soils used were :—

(a) Pusa soil, pH 8·1, a highly calcareous loam, containing about 30 per cent. calcium carbonate.

(b) Kalol soil, pH 7·3, a heavy loam from northern Bombay.

(c) Chinsurah soil, pH 7·2, a clay from Chinsurah, Bengal.

(d) Jorhat soil I, pH 4·2, a cultivated, unlimed, unmanured soil from the Jorhat Farm, Assam. It is a light loam containing ·1 per cent N.

(e) Jorhat soil II, pH 5·6. As above from an uncultivated plot.

(f) Sialkot soil, pH 7·3, a heavy loam from Sialkot, Punjab.

Tables I-VIII show the progress of nitrification of cake and ammonium sulphate in the above soils when varying quantities of sodium carbonate were added. The figures are the number of milligrams nitrogen per 100 grms. soil in the form of nitrate, nitrite, and ammonia. When the amount of nitrite is below 0·5, the column for nitrites is omitted.

Table IX shows the progress of nitrification in Omelianski solution as influenced by sodium carbonate.

TABLE I.

Influence of sodium carbonate on the nitrification of ammonium sulphate in Pusa soil.

Number of weeks incubation	1			2			4		6		8		12		14
	NO_3	NO_2	NH_3	NO_3	NO_2	NH_3	NO_3	NH_3	NO_3	NH_3	NO_3	NH_3	NO_3	NH_3	NO_3
Soil + Amm. sulphate . .	4·5	12·0	12·4	15·6	6·0	3·6	12·0	4·0	15·6	6·4	14·4	6·0	Not determined		
Do. + ·05 per cent. Na_2CO_3.	3·0	7·2	12·0	10·8	10·4	4·0	16·8	4·4	21·6	6·4	19·2	6·4		„	
Do. +0·1 per cent. Na_2CO_3.	2·1	4·0	11·2	7·8	4·0	4·8	19·2	4·8	21·6	6·8	20·4	6·8		„	
Do. +0·2 per cent. Na_2CO_3.	1·2	2·1	12·8	1·7	0·7	9·2	15·6	5·2	21·6	5·6	26·6	4·8	19·2	4·4	14·4
Do. +0·3 per cent. Na_2CO_3.	..	..	..	0·9	0·1	19·6	0·9	16·8	1·2	16·4	1·2	14·8	10·8	6·4	9·0
Do. +0·4 per cent. Na_2CO_3.	..	..	..	0·8	..	18·0	0·9	14·0	0·9	14·0	1·2	12·4	1·1	9·6	6·0

TABLE II.

Influence of sodium carbonate on the nitrification of mustard cake in Pusa soil.

Number of weeks incubation	1			2			4		6		8	
	NO_3	NO_2	NH_3	NO_3	NO_2	NH_3	NO_3	NH_3	NO_3	NH_3	NO_3	NH_3
Soil + Cake	3·0	1·9	8·4	9·6	..	8·0	9·6	7·6	11·2	6·8	13·2	11·6
Do. + ·05 per cent. Na_2CO_3 .	3·0	1·9	8·0	10·8	..	8·0	9·6	7·2	13·3	6·8	13·8	10·4
Do. +0·1 per cent. Na_2CO_3 .	2·4	1·7	9·2	10·8	..	8·0	9·6	8·4	11·2	7·5	13·2	11·2
Do. +0·2 per cent. Na_2CO_3 .	1·2	0·5	11·6	3·6	5·2	8·4	9·6	8·8	11·2	7·4	15·0	10·8
Do. +0·3 per cent. Na_2CO_3 .	..	..	..	0·6	0·2	16·0	0·6	14·0	0·8	14·8	0·8	12·0
Do. +0·4 per cent. Na_2CO_3 .	..	..	..	0·6	0·3	16·0	0·5	14·0	0·6	14·0	0·9	12·0

There was no nitrification in the soils with 0·3 per cent. and 0·4 per cent. Na_2CO_3 in 14 weeks.

TABLE III.

Influence of sodium carbonate on the nitrification of ammonium sulphate in Kalol soil.

Number of weeks incubation	1		2			3			5		7		11		14	
	NO_3	NH_3	NO_3	NO_2	NH_3	NO_3	NO_2	NH_3	NO_3	NH_3	NO_3	NH_3	NO_3	NH_3	NO_3	NH_3
Soil + Ammon. sulphate .	1·8	27·6	5·1	..	20·4	9·6	..	17·4	13·2	15·0	13·2	13·8	14·4	13·2	19·2	10·8
Do. +·05 per cent. Na_2CO_3.	1·8	25·8	8·1	..	17·4	13·2	..	13·2	·6·8	11·4	1·0	10·8	·0·4	8·4	22·8	7·2
Do. +0·1 per cent. Na_2CO_3.	1·8	26·4	10·2	..	15·6	15·6	..	0·8	20·4	8·4	21·6	4·2	21·0	4·2	26·4	2·4
Do. +0·2 per cent. Na_2CO_3.	1·2	26·4	4·2	5·44	10·8	15·6	1·75	9·0	25·2	4·8	24·0	4·2	24·0	3·0	26·4	2·4
Do. +0·5 per cent. Na_2CO_3.	0·9	28·2	1·5	5·1	14·4	6·6	2·7	4·2	28·8	3·6	24·0	3·0	25·2	3·0	28·8	3·0
Do. +0·75 per cent. Na_2CO_3.	0·3	22·8	..	..	..	0·3	..	18·2	0·9	14·4	10·8	3·6	13·2	5·4	13·2	3·6
Do. +1·0 per cent. Na_2CO_3.	0·3	16·2	..	..	..	0·3	..	9·0	0·6	6·0	0·63	4·2	1·08	4·2	1·05	3·6

TABLE IV.

Influence of sodium carbonate on the nitrification of mustard cake in Kalol soil.

Number of weeks incubation.	1			2			3			5		8		14	
	NO_3	NO_2	NH_3	NO_3	NO_2	NH_3	NO_3	NO_2	NH_3	NO_3	NH_3	NO_3	NH_3	NO_3	NH_3
Soil + Cake . . .	2·1	0·21	20·4	10·2	..	7·8	13·2	..	4·2	14·4	3·0	19·2	4·8	22·8	4·2
Do. +0·05 per cent. Na_2CO_3.	3·0	0·74	18·0	15·0	..	2·4	16·2	..	2·4	15·6	2·4	19·8	3·6	21·6	6·0
Do. +0·1 per cent. Na_2CO_3.	1·8	1·0	19·2	14·4	0·1	4·2	14·4	..	2·4	15·6	3·6	20·4	6·0	24·0	3·6
Do. +0·2 per cent. Na_2CO_3.	0·6	0·6	21·6	8·4	3·1	2·4	16·2	..	3·0	18·0	3·0	21·0	4·2	24·0	4·2
Do. +0·5 per cent. Na_2CO_3.	0·6	0·5	25·8	1·8	4·3	6·0	6·6	4·3	4·8	18·0	3·0	21·6	4·8	21·6	3·6
Do. +0·75 per cent. Na_2CO_3.	0·3	..	16·2	..	..	..	0·3	..	16·8	0·6	12·0	0·6	7·8	0·5	4·2

Result with 1 per cent. No_2CO_3 was the same as with 0·75 per cent.

TABLE V.

Influence of sodium carbonate on the nitrification of cake in Chinsurah soil.

Number of weeks incubation	1		2		4		6		8		10	
	NO_3	NH_3	NO_3	NH_3	NO_3	NH_3	NO_3	NH_3	NO_3	NH_3	NO_3	NH_3
Soil + Cake	0	16·8	1·2	24·4	6·0	20·2	13·8	13·4	16·8	6·9	19·2	6·6
Do. +0·05 per cent. Na_2CO_3	0	16·1	1·2	26·0	6·0	21·0	15·0	13·4	18·0	5·9	22·4	5·4
Do. +0·1 per cent. Na_2CO_3 .	0	16·8	1·5	24·2	6·0	21·0	14·4	13·4	16·8	4·2	22·4	4·2
Do. +0·2 per cent. Na_2CO_3 .	0	21·0	1·5	26·9	7·8	19·3	14·41	3·4	16·8	8·4	24·0	4·2
Do. +0·5 per cent. Na_2CO_3	0	21·8	0·9	28·5	7·2	18·5	13·2	10·8	14·4	3·4	18·6	3·4
Do. +1·0 per cent. Na_2CO_3 .	0	23·5	0·6	30·2	3·0	22·7	8·4	8·4	10·8	4·2	12·9	3·4

TABLE VI.

Influence of sodium carbonate on the nitrification of ammonium sulphate in Jorhat soil No. I.

Number of weeks incubation	2		4		6		8		10		12	
	NO_3	NH_3	NO_3	NH_3	NO_3	NH_3	NO_3	NH_3	NO_3	NH_3	NO_3	NH_3
Soil + Ammon. sulphate . .	1·95	33·2	2·1	35·6	1·1	35·2	1·2	30·8	2·4	34·4	1·5	33·2
Do. +0·1 per cent. Na_2CO_3	2·25	33·6	3·0	34·0	3·0	30·8	4·8	27·2	5·4	28·0	5·4	21·2
Do. +0·2 per cent. Na_2CO_3	2·25	33·2	4·5	33·6	5·7	26·0	10·8	19·6	16·8	15·2	16·8	12·0
Do. +0·3 per cent. Na_2CO_3	2·25	35·2	2·0	36·0	1·5	30·8	1·4	34·0	3·0	33·2	5·4	24·8
Do. +0·4 per cent. Na_2CO_3	2·1	33·2	1·8	35·2	1·5	30·4	1·4	30·0	1·8	28·8	1·8	24·0

TABLE VII.

Influence of sodium carbonate on the nitrification of cake in Jorhat soil No. I.

Number of weeks incubation	2		4		6		8		10		12	
	NO_3	NH_3	NO_3	NH_3	NO_3	NH_3	NO_3	NH_3	NO_3	NH_3	NO_3	NH_3
Soil alone	2·4	5·2	3·9	3·2	4·2	2·8	3·0	2·8	5·7	2·8	6·3	2·0
Soil + cake	0·75	20·8	1·2	24·8	1·4	25·6	5·7	19·6	9·6	16·8	9·0	15·2
Do. +0·1 per cent. Na_2CO_3 .	1·2	25·2	3·0	22·4	15·6	8·8	16·2	5·6	15·6	4·8	16·8	2·4
Do. +0·2 per cent. Na_2CO_3 .	1·2	24·0	1·7	24·4	8·4	25·6	13·2	12·8	12·0	8·4	13·2	4·8
Do. +0·3 per cent. Na_2CO_3 .	1·4	21·6	1·4	21·6	1·5	26·0	2·1	23·6	1·5	23·6	2·1	22·8

When 0·4 per cent. and 0·5 per cent. Na_2CO_3 were added, the figures of nitrate were slightly less than with 0·3 per cent.

TABLE VIII.

Influence of sodium carbonate on the nitrification of mustard cake in Jorhat soil No. II.

Number of weeks incubation	2		4			6			8			10	
	NO_3	NH_3	NO_3	NO_2	NH_3	NO_3	NO_2	NH_3	NO_3	NO_2	NH_3	NO^2	NH_3
Soil + cake	0·6	20·4	4·8	..	16·4	7·2	..	9·6	18·0	..	6·8	16·8	1·6
Do. +0·1 per cent. Na_2CO_3 .	10·8	5·2	12·6	..	1·6	20·4	..	1·6	19·2	..	2·4	19·2	2·4
Do. +0·2 per cent. Na_2CO_3 .	Trace	15·2	Trace	1·12	15·8	1·5	1·4	3·2	1·8	5·0	3·2	19·2	1·8
Do. +0·3 per cent. Na_2CO_3 .	Trace	18·8	..	..	20·6	..	..	19·2	..	..	17·2	..	9·6

There was no nitrification when 0·4 per cent. and 0·5 per cent. $NaCO_3$ were added.

TABLE IX.

Influence of sodium carbonate on nitrification in Omeliansky's solution.

The solution was inoculated with 1 grm. Pusa soil.

Number of weeks incubation	2		4		6		8	
	NO_3	NO_2	NO_3	NO_2	NO_3	NO_2	NO_3	NO_2
Omeliansky solution	0·75	0·5	4·5	..	10·0	..	14·0	..
Do. +0·05 per cent. Na_2CO_3.	..	3·3	1·0	3·6	6·5	..	11·0	..
Do. +0·1 per cent. Na_2CO_3.	..	..	..	2·0	3·8	..	7·0	..
Do. +0·2 per cent. Na_2CO_3.	..	..	..	..	..	1·1	1·8	2·6

There was no nitrification when 0·5 per cent. Na_2CO_3 was added.

Examination of the results shows that in Pusa soil the nitrification of cake was unaffected by concentrations of sodium carbonate below 0·2 per cent., was depressed for two weeks by 0·2 per cent., but recovered by the fourth week, and was suppressed by 0·3 per cent. or more. The nitrification of ammonium sulphate was depressed by all concentration for two weeks, but from the fourth week a stimulating effect was shown by concentrations up to 0·2 per cent. With a concentration of 0·3 per cent., nitrification was suppressed for eight weeks, and by one of 0·4 per cent. for twelve weeks.

In Kalol soil nitrification of ammonium sulphate was stimulated by concentrations up to 0·2 per cent. Na_2CO_3 from the second week's incubation. With 0·5 per cent. Na_2CO_3, depression was followed by stimulation at the end of the fifth week. With 0·75 per cent. Na_2CO_3, no nitrification was observed till the seventh week, and with 1 per cent. Na_2CO_3, none was observed in fourteen weeks.

The nitrification of cake was less affected than that of ammonium sulphate by concentrations up to 0·5 per cent., but when higher concentrations were added, it had not started after fourteen week's incubation.

In Chinsurah soil, amounts of sodium carbonate up to 0·5 per cent. had little influence on the nitrification of cake ; even when 1 per cent. was added nitrification was active after the fourth week.

In Jorhat soil No. I, nitrification of ammonium sulphate, which was practically absent when no sodium carbonate was added, was greatly stimulated by 0·2 per cent. Na_2CO_3. 0·3 per cent. sodium carbonate caused no improvement till the tenth week and with 0·4 per cent. there was no nitrification in twelve weeks. With cake, 0·1 per cent. Na_2CO_3 stimulated nitrification vigorously, and 0·2 per cent. rather

less so. Nitrification was inhibited by concentrations of 0·3 per cent. and over. In Jorhat soil No. II, 0·1 per cent. Na_2CO_3 stimulated the nitrification of cake, 0·2 per cent. held it in check for eight weeks, after which it was very active. Nitrification was absent when 0·3 per cent. Na_2CO_3 was added.

In Omeliansky solution, inoculated with Pusa soil, the smallest dose, 0·05 per cent. Na_2CO_3, diminished the amount of nitrification.

The influence of sodium sulphate on nitrification is illustrated in tables X-XVII and that of sodium chloride in tables XVIII-XXIV.

TABLE X.

Influence of sodium sulphate on the nitrification of ammonium sulphate in Pusa soil.

Number of weeks incubation	1			2			4		6		8			12		14	
	NO_3	NO_2	NH_3	NO_3	NO_2	NH_3	NO_3	NH_3	NO_3	NH_3	NO_3	NO_2	NH_3	NO_3	NH_3	NO_3	NH_3
Soil + Ammon. sulphate	5·4	1·8	12·8	19·2	1·4	3·2	21·6	2·4	21·6	4·0	21·6	..	3·2	21·6	1·2	..	..
Do. +0·1 per cent. Na_2SO_4.	2·7	1·8	11·6	16·8	1·8	4·0	21·6	3·2	24·0	4·0	24·0	..	3·6	24·0	3·6	..	..
Do. +0·2 per cent. Na_2SO_4.	1·5	1·6	13·2	14·4	1·8	7·6	21·6	3·6	24·0	3·6	24·0	..	3·6	21·6	4·0	..	..
Do. +0·5 per cent. Na_2SO_4.	..	0·7	23·2	2·4	2·0	14·8	21·6	3·6	24·0	4·0	24·0	..	4·0	24·0	4·0	..	..
Do. +0·75 per cent. Na_2SO_4.	..	0·2	23·2	..	0·5	21·6	..	19·6	8·4	14·8	21·6	..	5·6	21·6	5·2	..	..
Do. +1·0 per cent. Na_2SO_4.	..	0·1	23·2	..	0·2	22·0	..	20·0	..	20·0	..	2·1	17·6	16·8	4·8	24·0	4·0

TABLE XI.

Influence of sodium sulphate on the nitrification of mustard cake in Pusa soil.

Number of weeks incubation	2			4		6		8			12		16	
	NO_3	NO_2	NH_3	NO_3	NH_3	NO_3	NH_3	NO_3	NO_2	NH_3	NO_3	NH_3	NO_3	NH_3
Soil + cake. . . .	9·6	..	7·2	10·8	6·4	12·0	6·8	12·0	..	6·4	13·5	7·6	19·2	7·6
Do. +0·1 per cent. Na_2SO_4.	9·6	..	7·2	12·0	6·4	13·2	6·0	12·0	..	6·0	15·0	6·4	21·6	6·8
Do. +0·2 per cent. Na_2SO_4.	6·0	1·4	7·2	10·8	6·0	12·0	5·6	12·0	..	6·0	15·0	7·6	19·2	6·8
Do. +0·5 per cent. Na_2SO_4.	1·4	1·8	8·4	9·6	6·0	12·0	6·0	12·0	..	6·0	15·0	6·5	21·6	6·8
Do. +0·75 per cent. Na_2SO_4.	..	..	11·6	..	12·8	1·1	12·8	4·2	2·2	8·0	10·8	8·8	19·2	6·8
Do. +1·0 per cent. Na_2SO_4.	..	..	12·0	..	12·8	..	12·8	..	0·2	12·8	9·6	8·8	16·8	8·4

TABLE XII.

Influence of sodium sulphate on the nitrification of ammonium sulphate in Chinsurah soil.

Number of weeks incubation	4		8		12	
	NO_3	NH_3	NO_3	NH_3	NO_3	NH_3
Soil + Ammonium sulphate . . .	5·4	20·8	9·6	18·5	15·0	11·8
Do. + 0·2 per cent. Na_2SO_4 .	2·4	21·0	6·0	18·5	12·0	14·3
Do. + 0·4 per cent. Na_2SO_4 . .	1·2	23·6	5·4	21·9	10·8	16·8

TABLE XIII.

Influence of sodium sulphate on the nitrification of cake in Chinsurah soil.

Number of weeks incubation	4		8		12	
	NO_3	NH_3	NO_3	NH_3	NO_3	NH_3
Soil + cake	3·6	12·7	6·6	16·8	12·0	10·1
Do. + 0·2 per cent. Na_2SO_4 . .	1·8	14·3	3·9	16·0	10·8	10·9
Do. + 0·4 per cent. Na_2SO_4 . .	0·9	14·3	3·0	15·1	8·4	11·8

TABLE XIV.

Influence of sodium sulphate on the nitrification of ammonium sulphate in Sialkot soil.

Number of weeks incubation	4		8		12	
	NO_3	NH_3	NO_3	NH_3	NO_3	NH_3
Soil + Ammonium sulphate . . .	15·6	9·4	36·0	5·0	33·0	3·4
Do. + 0·2 per cent. Na_2SO_4 . .	14·4	7·6	31·2	5·9	28·8	4·2
Do. + 0·4 per cent. Na_2SO_4 . .	14·4	8·4	28·8	5·9	26·4	4·2

TABLE XV.

Influence of sodium sulphate of the nitrification of cake in Sialkot soil.

Number of weeks incubation	4		8		12	
	NO_3	NH_3	NO_3	NH_3	NO_3	NH_3
Soil + cake	19·2	8·4	31·5	5·9	29·6	4·2
Do. + 0·2 per cent. Na_2SO_4 .	18·0	8·5	28·8	5·0	26·4	4·2
Do. + 0·4 per cent. Na_2SO_4 .	16·8	10·8	26·4	5·9	24·0	4·2

TABLE XVI.

Influence of sodium sulphate on the nitrification of mustard cake in Jorhat soil No. I.

Number of weeks incubation	2		4		8		10		12	
	NO_3	NH_3	NO_3	NH_3	NO_3	NH_3	NO_3	NH_3	NO_3	NH_3
Soil + cake . . .	1·72	1·2	1·1	23·2	1·5	22·8	4·8	21·2	9·6	14·4
Do. + 0·2 per cent. Na_2SO_4 . .	1·35	22·8	0·8	23·6	1·4	27·6	0·6	26·4	1·6	24·4
Do. + 0·2 per cent. $CaCO_3$ . .	1·5	22·4	3·9	21·6	14·4	2·4	16·8	2·8	20·4	2·4
Do. + 0·2 per cent. $CaCO_3$ + 0·2 per cent. Na_2SO_4 .	1·5	22·8	0·6	22·4	13·2	8·4	16·8	2·0	18·0	1·6

TABLE XVII.

Influence of sodium sulphate on the nitrification of mustard cake in Jorhat soil No. II.

Number of weeks incubation	2		4		7		8	
	NO_3	NH_3	NO_3	NH_3	NO_3	NH_3	NO_3	NH_3
Soil + cake	..	18·8	1·2	18·8	8·4	9·2	16·8	6·8
Do. + 0·2 per cent. Na_2SO_4	..	19·6	0·6	21·2	6·6	15·6	13·2	11·2
Do. + 0·5 per cent. Na_2SO_4	..	..	1·2	20·0	..	..	12·0	7·6
Do. + 0·06 per cent. $CaCO_3$	0·6	16·0	6·3	13·2	16·8	3·6	19·2	2·4
Do. + 0·06 per cent. $CaCO_3$ + 0·2 per cent. Na_2SO_4	..	16·4	6·0	14·0	14·4	8·8	15·6	4·0

Examination of the figures shows that in Pusa soil, the initial depression even with the addition of 0·5 per cent. sodium sulphate had been made good by the fourth to sixth week. There was inhibition of nitrification up to the sixth week when 0·75 per cent., and to the eighth week when 1·0 per cent. of the salt was added, after which it proceeded vigorously.

In Chinsurah soil, nitrification was depressed by 0·2 per cent. sodium sulphate and rather more so by 0·4 per cent.; after 12 weeks about 50 per cent. more nitrate was recovered when no salt was added than was found in the soil with 0·4 per cent. salt.

In Sialkot soil the depression with quantities up to 0·4 per cent. salt was small.

Jorhat soil No. I is acid, and no increase in nitrate was found till the tenth week of incubation. Addition of 0·2 per cent. sodium sulphate prevented nitrification for 12 weeks. When 0·2 per cent. calcium carbonate was added to reduce the acidity of the soil, nitrification was much more vigorous, and after the fourth week, was very slightly affected by the addition of 0·2 per cent. sodium sulphate.

In Jorhat soil No. II, there was a small depression in the nitrate figures when 0·2 per cent. sodium sulphate was added.

TABLE XVIII.

Influence of sodium chloride on the nitrification of ammonium sulphate in Pusa soil.

Number of weeks incubation	1			2			4		6		8		12		16	
	NO_3	NO_2	NH_3	NO_3	NO_2	NH_3	NO_3	NH_3	NO_3	NH_3	NO_3	NH_3	NO_3	NH_3	NO_2	NH_3
Soil + Amm. sulphate	5·2	2·4	12·4	16·8	1·4	2·8	21·6	4·8	19·2	3·2	24·0	2·4	24·0	2·8	..	..
Do. + 0·1 per cent. NaCl.	0·9	2·2	15·2	21·6	1·4	4·0	21·6	5·2	16·8	4·0	21·6	2·8	21·6	3·2	..	..
Do. + 0·2 per cent. NaCl.	*	2·0	19·6	19·8	1·8	10·4	19·2	3·2	14·4	2·8	19·2	2·8	19·2	3·6	..	..
Do. + 0·4 per cent, NaCl.	..	0·4	22·8	6·0	0·7	21·6	1·4	20·4	5·4	13·6	12·0	4·0	12·0	4·8	19·2	5·2
Do. + 0·6 per cent. NaCl.	..	0·2	23·6	2·7	0·3	19·2	..	21·6	1·1	21·2	10·8	4·0	10·8	5·2	19·2	5·2
Do. + 1·0 per cent. NaCl.	..	*	24·8	2·4	..	23·2	..	22·0	..	22·0	*	19·6	6·0	5·6	12·0	5·2

* Traces.

TABLE XIX.

Influence of sodium chloride on the nitrification of cake in Pusa soil.

Number of weeks incubation	1			2			4			6			8		12	16
	NO_3	NO_2	NH_3	NO_3	NO_2	NH_3	NO_3	NO_2	NH_3	NO_3	NO_2	NH_3	NO_3	NO_2	NO_3	NO_3
Soil + cake . .	2·4	1·0	9·6	0·6	*	12·0	14·4	*	6·4	14·4	*	6·0	14·4	0·1	19·2	..
Do. +0·1 per cent. NaCl.	0·8	0·8	8·8	3·0	1·4	12·5	9·6	*	6·0	8·4	*	6·0	8·4	0·1	12·0	..
Do. + 0·2 per cent. NaCl.	*	0·6	10·4	1·1	2·0	12·8	6·0	0·1	8·0	6·6	*	6·4	9·6	0·1	9·6	16·8
Do. + 0·4 per cent. NaCl.	..	0·1	10·8	*	0·3	17·2	..	0·9	13·6	4·2	*	8·0	6·6	0·1	6·0	12·0
Do. +0·6 per cent. NaCl.	..	*	10·4	..	0·1	19·2	..	0·1	13·2	0·6	1·8	9·6	5·4	0·1	6·6	10·8
Do. + 1·0 per cent. NaCl.	..	*	10·4	..	*	20·0	..	*	13·6	..	0·1	13·6	*	4·4	4·8	9.6

* Traces.

TABLE XX.

Influence of sodium chloride on the nitrification of ammonium sulphate in Chinsurah soil.

Number of weeks incubation	4		8		12	
	NO_3	NH_3	NO_3	NH_3	NO_3	NH_3
Soil + $(NH_4)_2$ SO	5·4	20·8	9·6	18·5	15·0	11·8
Do. + 0·2 per cent. NaCl . .	0·9	29·4	3·6	25·2	6·6	17·4
Do. + 0·5 per cent. NaCl . .	0·9	29·4	2·4	27·7	5·4	21·0

TABLE XXI.

Influence of sodium chloride on the nitrification of cake in Chinsurah soil.

Number of weeks incubation	4			8			12	
	NO_3	NO_2	NH_3	NO_3	NO_2	NH_3	NO_3	NH_3
Soil + cake . . .	3·6	0·02	12·7	6·6	0·1	16·8	12·0	10·1
Do. + 0·2 per cent. NaCl.	0·0	0·15	16·8	2·4	0·4	16·0	7·5	11·8
Do. + 0·5 per cent. NaCl.	0·0	0·01	16·8	1·8	0·0	16·8	6·0	11·8

TABLE XXII.

Influence of sodium chloride on the nitrification of ammonium sulphate in Sialkot soil.

Number of weeks incubation	4		8		12	
	NO_3	NH_3	NO_3	NH_3	NO_3	NH_3
Soil + $(NH_4)_2SO_4$	15·6	9·4	36·0	5·0	33·0	3·4
Do. + 0·2 per cent. NaCl . .	6·6	16·8	14·4	5·9	18·0	5·0
Do. + 0·5 per cent. NaCl . .	0·0	27·7	10·8	5·9	12·0	6·7

TABLE XXIII.

Influence of sodium chloride on the nitrification of cake in Sialkot soil.

Number of weeks incubation	4			8			12	
	NO_3	NO_2	NH_3	NO_3	NO_2	NH_3	NO_3	NH_3
Soil + cake . . .	19·2	0·04	8·4	31·5	0·12	5·9	29·6	4·2
Do. + 0·2 per cent. NaCl.	9·6	0·06	9·2	19·5	0·08	5·9	16·8	5·0
Do. + 0·5 per cent. NaCl.	3·6	0·14	25·2	15·0	0·08	6·7	10·8	5·0

TABLE XXIV.

Influence of sodium chloride on the nitrification of mustard cake in Jorhat soil No. II.

Number of weeks incubation	4		6		12	
	NO_3	NH_3	NO_3	NH_3	NO_3	NH_3
Soil + cake.	1·2	18·8	16·8	6·8	15·6	4·0*
Do. + 0·1 per cent. NaCl . .	1·1	20·8	12·0	9·6	9·0	8·8
Do. + 0·2 per cent. NaCl . .	0·6	22·4	3·6	7·6	2·6	8·4
Do. + 0·4 per cent. NaCl . .	†	23·8	1·4	22·4	3·9	14·8

* 10 weeks. † Traces.

In Pusa soil, the slight stimulation of nitrification of ammonium sulphate in the second week by the addition of 0·1 per cent. or 0·2 per cent. sodium chloride is

not maintained, and is followed by a slight depression. Increasing toxicity is shown by higher quantities. The toxicity of 0·1 per cent. sodium chloride to the nitrification of cake is evident, but even 1 per cent. sodium chloride did not entirely prevent nitrification, which had started by the twelfth week's incubation.

In Chinsurah and Sialkot soils, 0·2 per cent. sodium chloride markedly checked nitrification, but not so severely as in Jorhat soil No. II.

Summary.

The manner in which nitrification in soil was influenced by sodium carbonate depended on the nature of the soil, and to a lesser extent, upon whether cake or ammonium sulphate was being nitrified.

In Pusa soil, 0·2 per cent. sodium carbonate, showed toxic effects for two weeks, after which nitrification caught up to, and with ammonium sulphate, surpassed that of the control. 0·3 per cent. was distinctly toxic.

In the Jorhat soils, which are acid, the initial doses of sodium carbonate, by lowering the acidity, increased nitrification, but 0·3 per cent. suppressed the nitrification of cake, and 0·4 per cent. that of ammonium sulphate.

In Kalol soil, initial depression was followed by stimulation, when 0·5 per cent. sodium carbonate was added. 0·75 per cent. retarded the nitrification of ammonium sulphate, and entirely suppressed that of cake.

There was some stimulation of nitrification in Chinsurah soil by additions up to 0·2 per cent.; 0·5 per cent. had little effect, and even when 1 per cent. was added nitrification was vigorous, for its addition produced about two-thirds of the amount of nitrate found in the control soil.

Except in Pusa soil, 0·2 per cent. sodium sulphate showed some toxic effect, which increased as the dose of sodium sulphate increased. In Pusa soil, the initial depression caused by the addition of 0·2 per cent., and even of 0·5 per cent., lasted only a short time, after which nitrification proceeded as vigorously as in the control. 1 per cent. sodium sulphate prevented nitrification for eight weeks, after which nitrate accumulation was rapid.

Sodium chloride, 0·2 per cent. depressed nitrification, except that of ammonium sulphate in Pusa soil, where its influence was slight. 0·1 per cent. depressed the nitrification of cake in both Pusa soil and Jorhat soil No. II.

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FOOD REQUIREMENTS OF CROPS WITH REFERENCE TO SOUTH INDIAN SOILS.*

BY

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(With plates LIV to LV and two text-figures.)

Although plants require a number of elements for normal growth and reproduction, in agricultural practice the supply of plant food elements is restricted to nitrogen, phosphorus and potassium as these are absorbed in relatively large quantities. The soil ordinarily contains sufficiently large reserves of the other elements and does not need replenishment. Occasional applications of lime may, however, be indicated in certain localities. The discussion is, therefore, confined to the supply of the more important constituents, namely, nitrogen, phosphoric acid and potash.

The food requirements of crops may be discussed from many points of view. I am here limiting myself to the consideration of the effects of different forms of food-supply on :—

1. the growth and the yield of crop,
2. the composition of the crop,
3. the vegetative and reproductive capacity of the seed,

and 4. the nutritive value of the crop.

The observations made hereunder are based on the results of experimental work done at Coimbatore, although, judging from the direct and indirect confirmations elsewhere, they are of wider applicability.

1. Manuring with reference to Yeld.

Norris [1923] in his "Note on the Permanent Manurial Plots at Coimbatore" discussed the results of 36 successive crops taken off the plots that have been continuously manured with cattle manure or with ammonium sulphate, superphosphate, and potassium sulphate, singly and in different combinations. In the earlier crops,

* Contribution to the joint discussion by the Agricultural and Botanical sections of the Indian Science Congress, Nagpur, 1931.

there was no great difference in the yields from the plots to which nitrogen, phosphoric acid and potash were applied singly. As would be expected, the yields from plots receiving nitrogen were more than those from plots receiving either potash or phosphate. A definite change was, however, noticed after 18 crops were harvested. Comparing the yields from unmanured plots with those from manured plots, the yields from the 19th crop showed differences in favour of plots receiving phosphate singly or in combination with either nitrogen or potash. This difference kept on increasing as the experiment continued. The relative yields of crops as recorded by Norris [1923] in the Memoir referred to above are extracted below :—

Relative yields (No manure=100).

	Cholam (*Andropogan Sorghum*)		Ragi (*Eleusine coracana*)		Wheat (*Triticum vulgare*)	
	Grain	Straw	Grain	Straw	Grain	Straw
No manure . . .	100	100	100	100	100	100
N.	112	126	170	165	157	135
K.	123	143	300	200	138	126
P.	232	163	529	286	161	137
N *plus* P	292	191	812	449	224	195
N *plus* K *plus* P . .	275	192	903	548	246	230
N *plus* K . . .	111	140	226	181	158	120
K *plus* P	253	167	675	414	194	183

It is evident that phosphate had become a limiting factor in these plots. There was response to nitrogen but it was much less than that due to phosphate. In the case of plots receiving no phosphates, the response to nitrogen was limited by the deficiency of phosphoric acid. This is clearly seen when the increases due to nitrogen and potash singly, and in combination between themselves, are compared.

The action of potash is not clear. While in the case of *cholam* and wheat it tended to show a depressing action, its beneficial effect on *ragi* was very marked.

Comparing cattle manure with mineral manure, the average yields of crops manured separately with cattle manure and complete mineral manure, as against "No manure" at 100, are given for two periods. The first covers 36 crops which

formed the subject matter of the paper by Norris; and the second refers to the subsequent 20 crops.

	No manure		Complete mineral manure		Cattle manure	
	Grain	Straw	Grain	Straw	Grain	Straw
From the 1st to the 36th crop						
Cholam	100	100	292	191	295	192
Ragi	100	100	903	548	750	426
Wheat	100	100	246	230	171	191
From the 37th to the 56th crop						
Cholam	100	100	336	165	384	202
Ragi	100	100	429	402	409	479
Ranivaragu	100	100	377	306	461	370
Wheat	100	100	237	201	356	290
Cambodia cotton Kapas	100		133		191	

The effect of farmyard manure on the first 36 crops was generally inferior to that of the complete mineral manure. The averages for the 37th to 56th crops were, with the exception of those for *ragi*, distinctly in favour of farmyard manure. It may here be stated that for *ragi* it was only in the case of crop No. 38 that the yield from mineral manure plot was higher than that from farmyard manure plot. If this crop is cut out, the averages for the rest of the crops from farmyard manure plots are greater than those from mineral manure plots.

It would appear that artificial fertilisers show distinct superiority over farmyard manure in the earlier years of their application, and that in later years farmyard manure asserts itself in contributing to greater yields over artificial fertilisers. This conclusion is supported by the results of experiments at Rothamsted. Sir John Russell [1926], in his Hitchcock lectures in America, drew attention to this fact and showed how mineral manures were superior to farmyard manure in the earlier years of their application and how in later years the yields fell below those of farmyard manure plots.

It would also appear that mineral manures are capable of being better utilised in the presence of sufficient supplies of organic matter than when applied alone. The results of certain pot cultures with paddy in this direction are given below :—

	No manure	0·33
Artificials	Phosphate alone	0·50
	Nitrogen alone	0·70
	Nitrogen *plus* phosphate	0·90
	Green Manure	1·00
Artificials with organic manures.	Green manure *plus* phosphate	1·20
	Green manure *plus* nitrogen	1·33
	Green manure *plus* nitrogen *plus* phosphate	1·60

The proportion of grain to straw has also been found to vary with the nature of the manurial treatment.

Cholam—Ratio of grain to straw (Straw=100).

No manure plots	13·7
Non-phosphate plots	14·3
Phosphate plots	19·6
Cattle manure plots	23·7

Here again the proportion of grain to straw is greatest in the cattle manure and phosphate plots.

2. Manuring with Reference to the Composition of the Crop.

The chemical analyses of crops raised under different manurial conditions are given below :—

Average composition of cholam grain, per cent. on dry matter.

Nitrogen	Nitrogen plots	1·780	Phosphate plots	1·797
	Non-nitrogen plots	1·827	Non-phosphate plots	1·804
	Cattle manure plots	1·810		
Potash	Potash plots	0·433	Phosphate plots	0·452
	Non-potash plots	0·428	Non-phosphate plots	0·399
	Cattle manure plots	0·433		
Phosphate	Phosphate plots	0·801		
	Non-phosphate plots	0·568		
	Cattle manure plots	0·624		

It is clear that in regard to nitrogen there is no significant variation in the composition of the grain grown under any system of manurial treatment. The application of nitrogen has improved the crop yield but has not increased the store of nitrogen. In the case of potash also its percentage in the crop is not increased. It is, however, in the phosphate content of the crop that the most striking difference is noticed and that is in favour of the phosphate plots.

3. Manuring with Reference to the Vegetative and Reproductive Capacity of the Seed Material.

The most surprising observation is that manuring the parent crop alters the quality of the resulting seed in relation to its capacity for subsequent crop production in its next generation. Viswa Nath and Suryanarayana [1927] embodied the results of their investigations in this direction in a Memoir entitled "The Effect of Manuring a crop on the Vegetative and Reproductive capacity of the seed". These authors have shown that if the grain from the differently manured plots is used for seed purposes and sown in a soil of moderate fertility, the result-

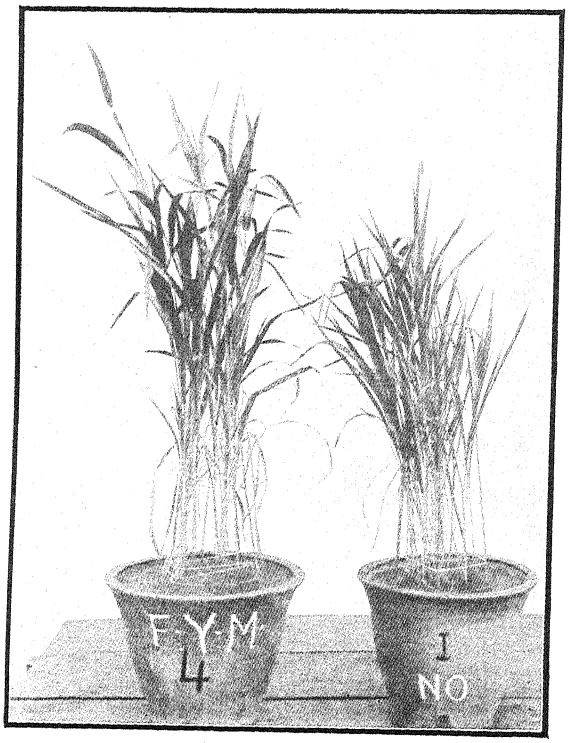


Fig. 1. Plants raised in unmanured soil from seeds raised from an unmanured crop (NO) and a crop manured with farmyard manure (F. Y. M.).

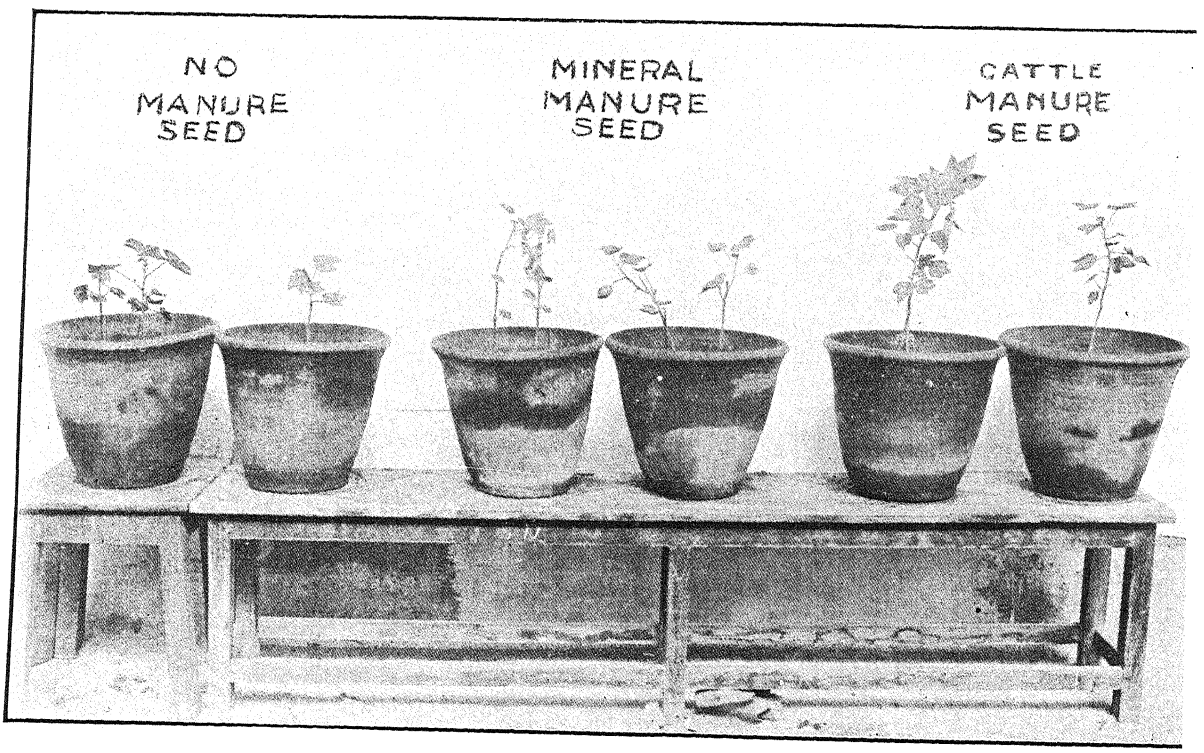
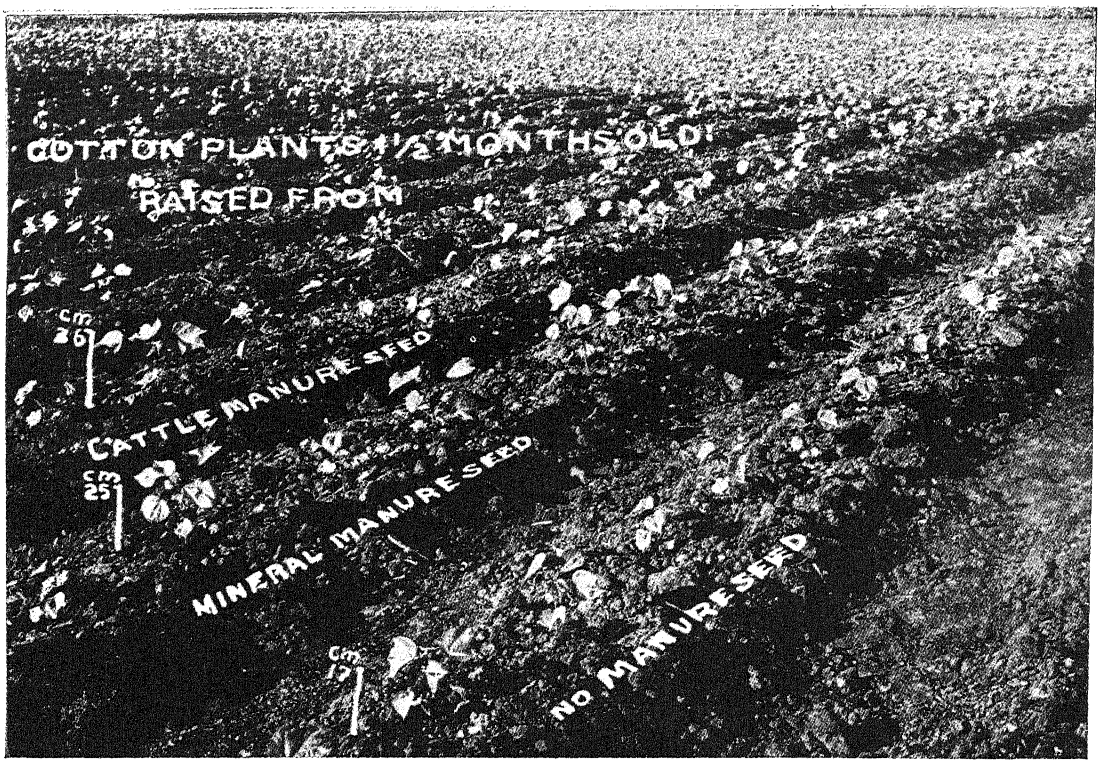


Fig. 2. Cotton plants grown from seeds whose parent crops were differently manured.



Cotton plants grown on field-scale from seeds whose parent crops were differently manured.

ing crops are different. The seed obtained from the cattle-manured plot gives a very much better crop than that manured with mineral manures or not manured at all. Some of the results of pot cultures by Viswa Nath and Suryanarayana [1927], are extracted from the Memoir quoted above. (Plates LIV, LV and Fig. 1.)

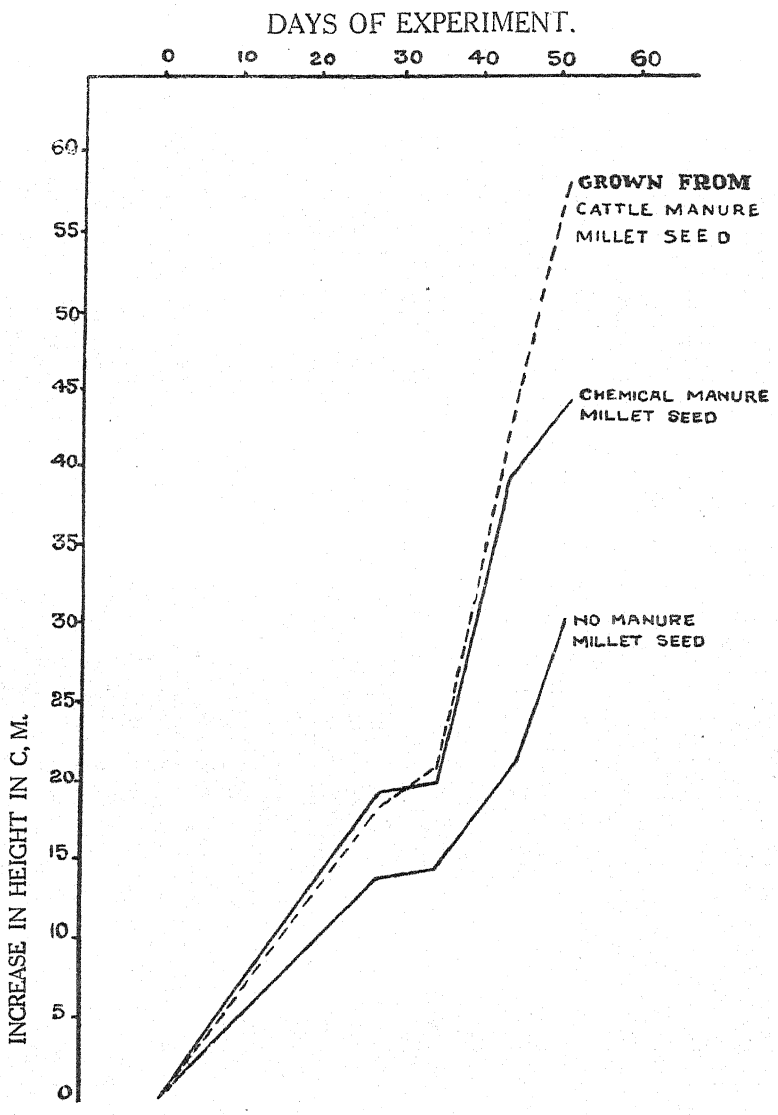


Fig. 1.

Rate of growth of plants raised from seeds whose parent crop was differently manured.

	CROP FROM THE SEED OF		
	No manure	Mineral manure	Cattle manure
Ragi	100	277·0	288·5
Ragi	100	143·2	173·2
Pain Varagu	100	132·8	197·7
Wheat	100	111·3	156·6

Further experiments with cotton and sugarcane and from seeds from other sources confirm these results, showing that the quality of the seed is influenced by the nature of the treatment given. On the face of it, this observation may be surprising, but if the analogy is stretched to seed selection from a standing crop, it is easy to realise that there is nothing extraordinary in the effect of nutrition on the quality of the seed. The great point of interest is in the superior effect of organic manures over mineral or chemical manures.

Since the publication of our results there has appeared evidence generally supporting our findings. Mr. Page,* formerly of the Rothamsted Experiment Station, mentions in a private communication that he observed differences in germination of wheat and barley under differently manured conditions. Rao Bahadur Venkataraman* reports similar observation in regard to the effect of manurial treatment in the germination and growth of differently manured sugarcane setts. Kruger [1927-28] in Germany reports that the quality of the seed potatoes is distinctly influenced by the application of fertilisers and that Moorland soils give the best, while heavy calcareous mineral soils give the worst types of seed potatoes. Kottmeier [1927] also from Germany carried out experiments with different manures including farmyard manure, and reports that manuring affects the quality of the potato seed. Breazeale [1927], of the Arizona University, records that fermented organic manures are capable of giving to plants certain vitamin-like substances.

4. Manuring with Reference to the Nutritive Value of the Crop.

The results of animal nutrition experiments carried out in association with Lieut.-Col. R. McCarrison [1926], show that a crop raised with cattle manure possessed better nutritive value than an unmanured crop or a crop raised with

*Private communications.

mineral manures. The grain from the crop manured with mineral manures possessed better nutritive value than the grain from an unmanured crop. Some of my own later experiments carried out at Coimbatore in 1930, by feeding rabbits with millet seedlings grown under differently manured conditions (Fig. 2) confirm the results of earlier experiments, carried out in association with Lieut.-Col. McCarrison [1926].

PERCENTAGE INCREASE IN WEIGHT OF RABBITS FED WITH DIFFERENTLY MANURED RAGI PLANTS

AUG.—OCT. 1930.

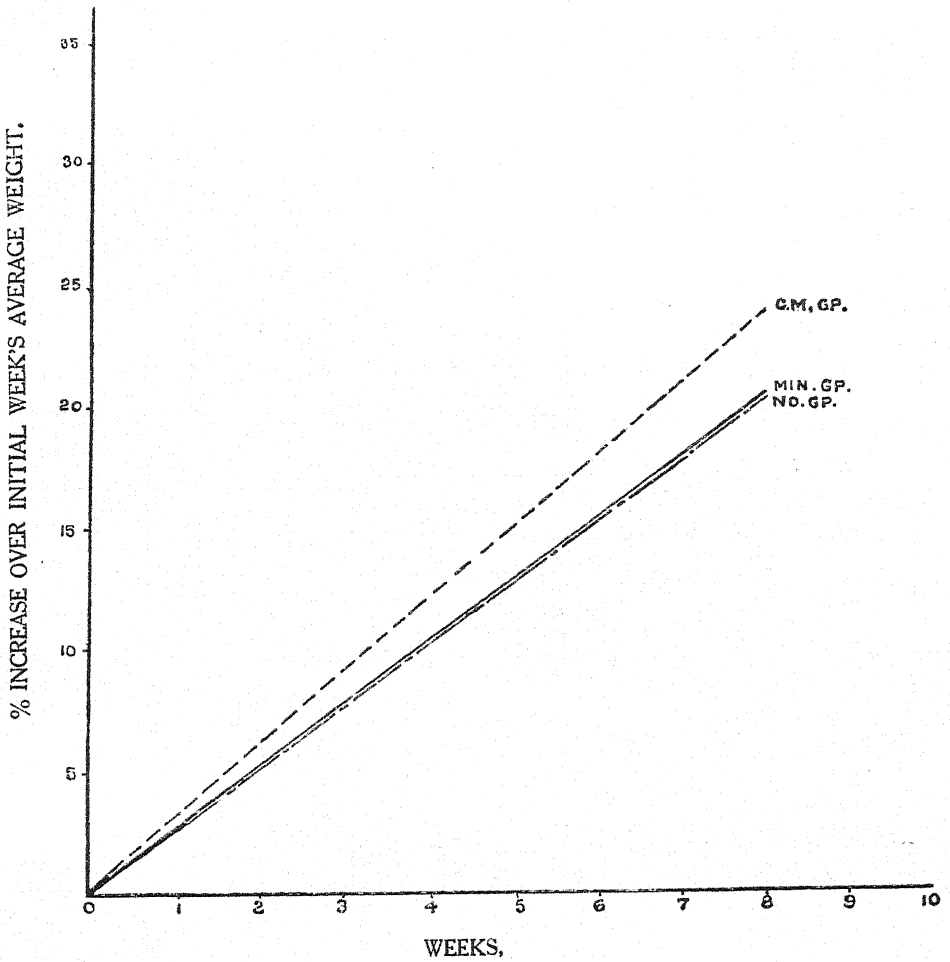


Fig. 2.

Further confirmation of our results is forthcoming from elsewhere.

In an article in *Science* [Anon., 1921], embodying the results of certain nutrition experiments, it was stated that the nutritive value of a crop varied with soil conditions. The results of Hunt's [1928] investigations at Ohio University on the influence of fertilisers on the nutritive value of wheat are in a line with those of ours. The latest confirmation is from England by Rolands and Wilkinson [1930], who carried out nutrition experiments with the knowledge of Professor Drummond. These investigators find that a crop raised with cattle-dung is very superior in its nutritive value to that of the crop raised with artificial fertilisers.

The evidence so far considered directs pointed attention to certain aspects of plant nutrition. The growth and quality of a crop is influenced by the nature of the food supplied to the plant, and that deficiencies in this direction would result in unbalanced nutrition. Although plants are capable of responding to applications of mineral fertilisers, they seem to thrive better in the presence of adequate supplies of organic matter.

The indirect benefits which organic matter confers on plant growth in improving the texture and the water-holding capacity of the soil and in providing food for soil bacteria are well-known. In addition to these indirect effects, organic matter appears to give the plant a better balanced nutrition and also in providing certain nutritional factors which the usual mineral fertilisers either do not provide or do so inadequately.

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STUDIES IN THE LIFE-HISTORIES OF THREE INDIAN SYRPHIDÆ.

BY

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(Received for publication on the 26th May, 1931.)

(With Plates LV to LVII.)

Introduction.

The family Syrphidæ presents various interesting and intricate problems. Being one of the largest families of Diptera, the insects belonging to it possess diverse habits and habitats, a knowledge of which will repay intensive study of the group.

The larvæ of Syrphidæ have been found on plants, in stems of certain plants and deriving food from them, predating on soft-bodied insects, such as Aleyrodidæ, Aphididæ and others, living symbiotically in the nests of Hymenoptera, in decaying wood or trees, in the flowing sap of diseased trees, in decaying vegetable and animal matter. Yet there are many more, the larval habits of which are very little known as yet.

The present account deals with the hitherto unknown immature stages of three species of Syrphidæ, *viz.*, *Ceria eumenoides*, Saund., *Helophilus curvigaster*, Macq., and *Eristalis quinquestriatus*, Fabr.

For references I have consulted freely 'Syrphidæ of Ohio' by C. L. Metcalf and the monumental work of Verrall on 'British Flies'.

Life History of Ceria Eumenoides, Saunders.

Introduction.

Ceria eumenoides, Saund. belongs to the Sub-family Cerianæ composed of wasp-like Syrphids in which the antennæ are porrect, long and set upon the produced frons; first posterior cell generally closed; third vein with a loop below into the first posterior cell, the loop usually provided with a small stump of a vein as in the Microdontinae; abdomen elongate, contracted more or less at the base as in wasps, and banded yellow.

The fly was described originally from Northern India. It has been reported from Kohat, N. W. Frontier; Matheran, Bombay Presidency, and from Chapra, Bihar. This species also occurs at Calcutta and in North Bengal (*Saunders*). To

this list of localities may be added Pusa (Bihar) where a gravid female and a male were caught on 15th April and 27th April 1930, respectively, while sitting on the flowing sap of a *Siris* (*Albizzia lebbek*) tree.

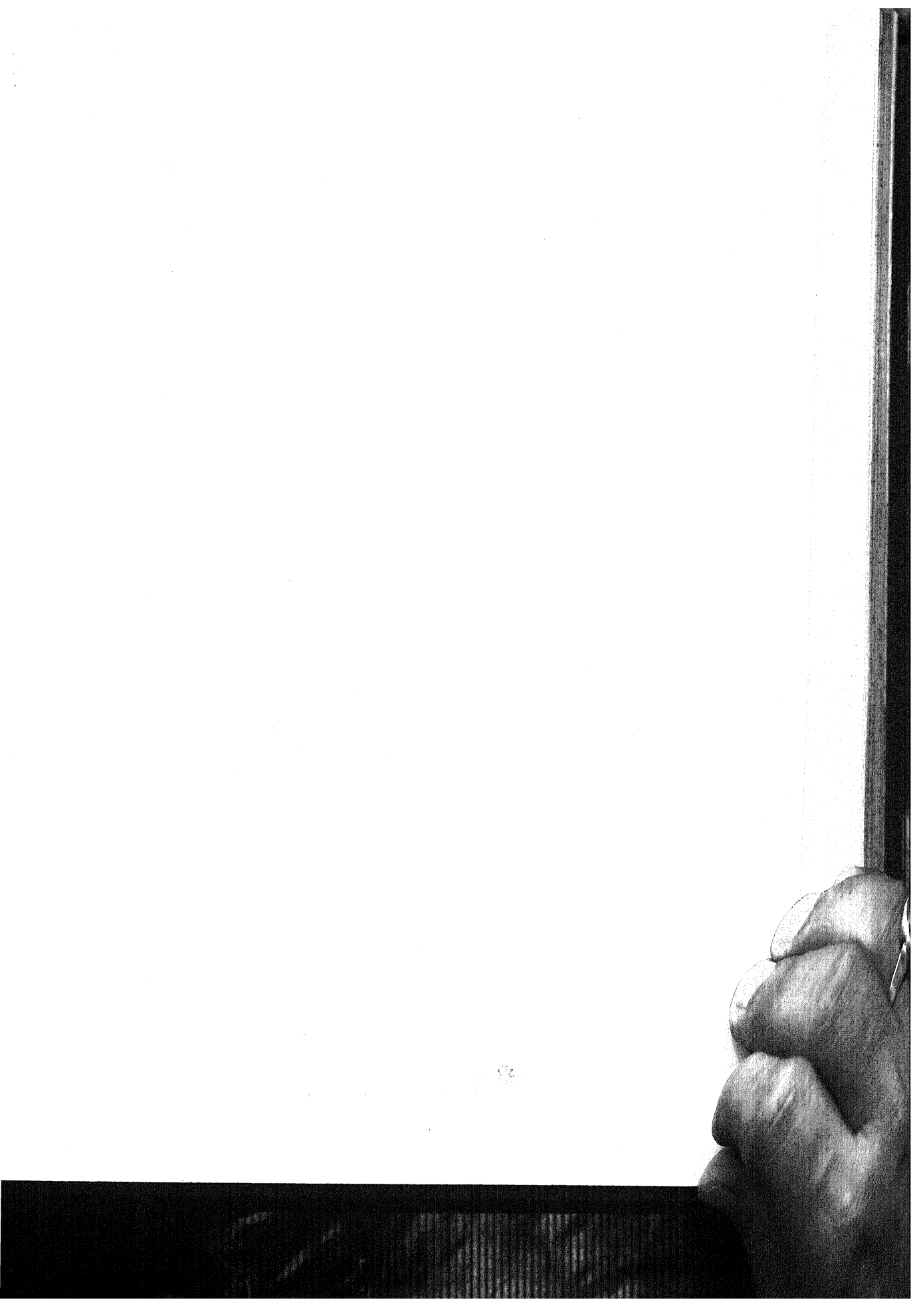
The flies have been known to breed in the sap of trees. Pupæ have been found in the bark and the sap of dead oaks. Verrall in his 'British Flies' (Vol. VIII, p. 665) says :—"The larvæ live in the sap of diseased trees such as Poplars (*Populus*), and in the sappy portions of Ulcers on Elms (*Ulmus*)".

Some observations.

A gravid female was seen at 1 P.M. on the 15th April 1930, sitting on the flowing sap of a *Siris* (*Albizzia lebbek*) tree, towards the base of its trunk. For about a minute or so it remained there, during which period the fly protruded and retracted its very long and segmented ovipositor twice or thrice after which the fly was netted and brought to the laboratory. In order to determine whether the fly could oviposit under laboratory conditions, it was liberated, on the same day at 3 P.M. in a wide-mouthed cage covered with a watch glass. A flat crucible containing soft blackish exudation from a *Siris* (*Albizzia lebbek*) was placed within the jar. The fly was fed on a sugary syrup placed below a leafy branch of *Siris* in a beaker with water within the jar. The fly when thus confined seemed to be at home and did not seem to feel its changed habitat. A few hours after liberation it fed on the syrup and was seen briskly flying about, cleaning its wings with the hind pair of legs and extruding its segmented ovipositor.

A single egg was laid at 10 A.M. on the 16th April. No more eggs were laid between 10 A.M. and 4 P.M. on the 16th April. Between 4 P.M. of the 16th April and 10 A.M. of the 17th April six eggs were observed, four on the under and upper surfaces of the leaves of the twig and two on the sides of the glass cage. In all 182 eggs were laid during the course of five days. The data bearing on the number of eggs laid each day, the dates of different layings and the dates of hatching are given below in tabular form :—

Date of egg laying	Number of eggs laid	Date of hatching
16th April 1930	One . . .	Did not hatch.
17th April 1930, 2 P.M. . . .	Six . . .	Four hatched at 10 A.M. on 19th April 1930.
18th April 1930, 10 A.M. . . .	Forty-five . .	Twenty-three hatched at 10 A.M. on 20th April 1930.
19th April 1930, 10 A.M. . . .	Sixty . . .	Thirty-three hatched at 10 A.M. on 21st April 1930.
20th April 1930, 11 A.M. . . .	Seventy . .	Twenty-eight hatched at 11 A.M. on 22nd April 1930.



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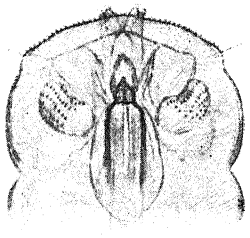

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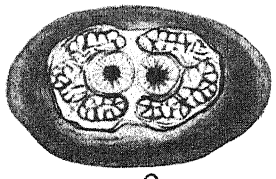

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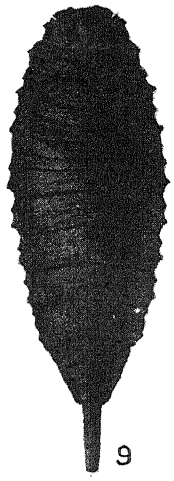

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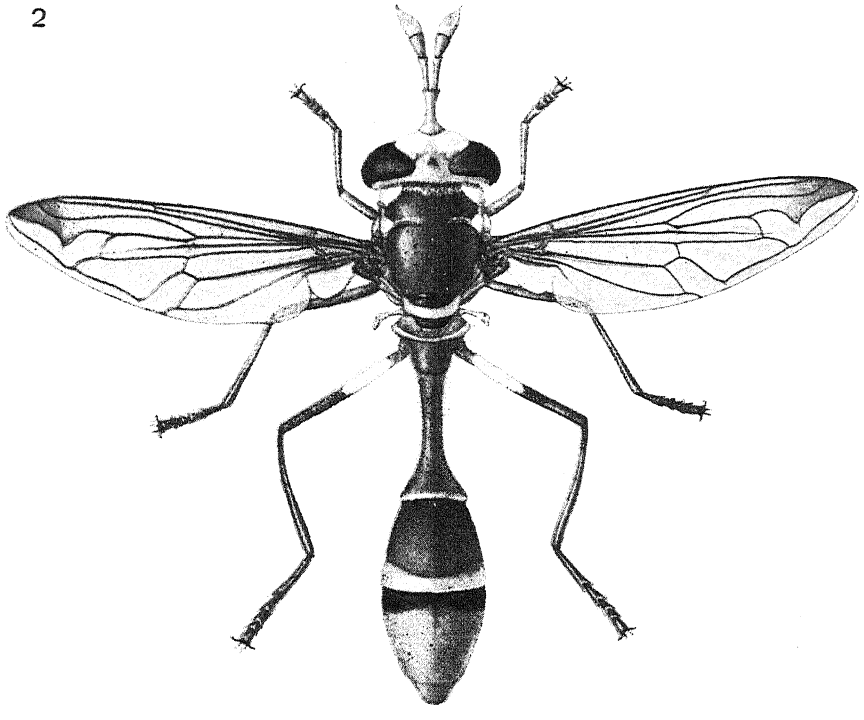

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CERIA EUMENOIDES, SAUNDERS

1. The egg × 12; 2, Chorion of the egg highly magnified; 3, Young larva × 12; 4, Full-grown larva × 4, 5, Ventral view of the head of the full-grown larva × 50; 6, Antenna; 7, Mouth-parts; 8, Posterior Spiracles of the larva × 54; 9, The pupa × 4; 10, The female adult fly × 4.

Life-History.

The egg.—(Plate LVI, fig. 1).

The eggs when laid are white, each measuring 1 mm. in length and 0·33 mm. in breadth. Each egg is roughly cigar-shaped being broader at one end and comparatively narrower at the other. The margins of the eggs are finely crenate. The surface is sculptured with convex areas appearing as small tuberculated processes when seen under a high magnification. Each of these convex areas encloses within it four to five reticulated cells.

The young Larva.—(Plate LVI, fig. 3).

The eggs hatch in forty-eight to sixty-four hours after oviposition. The young larva is white in colour measuring 2·5 mm. in length and 0·5 mm. in breadth. Its body is sub-cylindrical ending posteriorly in a chitinous tube carrying a pair of tracheal tubes, opening separately at its distal end by two posterior stigmata. The distal end of the chitinous tube is provided with a circlet of barbed hairs. The head is large with the oral aperture situated at its anteroventral aspect. The latter is guarded by a pair of flaps which, by introvertion and opening out, draw into the buccal cavity a current of water. The flaps possess strong recurved spines. Within the flaps or the lips as they may conveniently be called, is to be seen the striated, muscular, heart-shaped, chitinous termination of the oesophageal frame-work enclosing a hard, black chitinous structure homologous to the external mouth parts of phytophagous Syrphid larva. It consists of an inverted V-shaped chitinous structure the arms of which are bifurcated posteriorly. Each one of the two arms is thickened in the middle where it is connected with the other by a thin chitinous transverse piece.

The segments of the body cannot be clearly distinguished. Posterior to the head is the prothoracic segment bearing the anterior thoracic spiracles. After the prothoratic segment nine segments are faintly discernible, the last one followed by the chitinous tube. The larva is supplied with six pairs of parapodia which are muscular processes from the ventrolateral parts of the segments. With the aid of the muscular action of the body wall they are useful to the larva in crawling through the sap in which it lives. Each parapodium is studded with three strong, recurved spines besides other smaller ones.

Towards the posterior end on the ventral side is the anal aperture. It consists of a raised papilla guarded by twelve finger-like processes arranged round it in a palmate manner.

The tracheae are a pair of elastic white tubes strengthened by chitinous rings. They are longer than the body. They bend inwards about the middle of the body and, extending as far as thoracic segments, again bend inwardly, after which they break up into small branches aerating the head and the thoracic segments. The

tracheal tubes are continued separately into the chitinous tube as mentioned above.

The young larvæ when placed in water are in the habit of doubling up their bodies thereby suggesting their descent from aquatic forms. The larva, if submerged in water, tries to save itself by raising its tail end into the air. It does not feel comfortable when there is much water. Therefore, while breeding, care should be taken not to allow them excess of water.

The larvæ are negatively phototropic. Bright light is detrimental to their normal growth. This was observed when young larvæ were placed on a slide for observation. When maximum light was thrown from condensors placed suitably at proper angles, they became restless and began to move about. When subjected to strong light for some time, they succumbed to premature death.

Full grown larva.—(Plate LVI, fig. 4).

The full grown larva of *C. eumeniodes*, Saund., is 25 mm. long, 4·5 mm. broad, the respiratory tube being 3·5 mm. At the tip of the latter open the posterior stigmata as shown in the end view of the respiratory tube (Plate LVI, fig. 8). The larva is soft, brownish-yellow in colour, sub-cylindrical, with its ventral surface flat. In shape it is roughly fusiform, being broader at the anterior end and gradually tapering towards the posterior. The head is broad, ornamented by a row of papilliform spines on the anterior margin. These spines are believed to be sensory* in function. The oral aperture, situated on the ventral side of the head, is guarded by a pair of well-developed lips which are simultaneously introverted and extruded with the muscular movements of the body. The mouth-parts in the adult larva are somewhat atrophied.

The tracheæ are a pair of white tubes running throughout the entire length of the body of the larva and are seen to open posteriorly into a pair of stigmata which are ornamented with a circlet of barbed bristles. The anterior spiracles are situated at the summit of the anterior larval respiratory cornua which are a pair of small orange-coloured chitinous processes situated one on each side at the junction of the head and the prothorax.

The number of body segments is indistinct. The body is marked by groups of transverse folds dorsally and bears on the ventral side six pairs of prolegs which are well developed in the adult larva. Judging from the folds and the prolegs one can count ten segments excluding the head. This is arrived at by counting six segments for the six pairs of prolegs and behind the last segment bearing prolegs there are

* Buckton, G. B. in his book "The Natural History of *Eristalis tenax*", p. 21, says that the larvæ "appear indeed to be cognizant of little more than the single sense of touch and this is mostly confined to the region round the blunt projecting tubercles placed on what may be considered as the head of the maggot. The rounded parts are thickly clothed with minute capitate papillæ".

three clear segments and adding to these the prothoracic segment, the total comes to ten. Metcalf [1913] says that there are twelve segments in the body of the aphidiphagous larvæ and while homologizing the number of segments in the aphidiphagous larvæ with those that are present in *Eristalis* larva, supposes two segments for the posterior respiratory appendage in *Eristalis* and ten segments for the rest of the body.

In the larva of *C. eumenoides* there are ten segments excluding the head and the posterior respiratory appendage. If we take one segment for the post-respiratory appendage, as apparently it consists of one segment only, and two for the head, the total number of segments in the body of the larva comes to thirteen instead of twelve as in aphidiphagous larvæ and that of *Eristalis*.

The anal aperture is situated on the ventral side at the junction of the eighth and the ninth segments. The ninth segment bears a pair of small lateral processes. The tenth segment is also provided with a pair of well-developed fleshy processes one on each side at the base.

Spines are not present on the body segments of the larva. They are only seen on the prolegs, the lips and the anterior margin of the head.

Posterior Stigmata (Plate LVI, fig. 8).—The tracheal tubes, although approximating along the median line, open by separate apertures. There are only two spiracles and not more as in aphidiphagous larvæ. The dorsal* plate of the aphidiphagous larva is absent. Around each spiracle in the end view of the chitinous tube there is seen a circular chitinous area which is divided into a large number of small parts by radial lacunæ emerging from the centre and gowing right up to the periphery. Each chitinous circular area is ornamented on the outer side with a semi-circular honeycomb-shaped chitinous structure clearly divisible into three parts as shown in the figure.

Pupa (Plate LVI, fig. 9).—The larva under laboratory conditions continues to grow for about thirteen weeks after which it pupates. The pupa is dark brown in colour, 17 mm. long and 5 mm. broad, the respiratory tube being 2 mm. long. It has much the same appearance as the full-grown larva, but for the following few characters. The dorsal surface of the pupa is marked by a convexity which is more pronounced than in the larva. This convexity of the surface decreases at the two ends. The larva, when fully matured and about to pupate, develops small tubercles on the body. These are more prominent laterally than on the dorsal surface and can easily be seen in the pupa. The corrugations on the body are as in the larva, but the segmentation is not distinct.

To facilitate respiration, each anterior spiracle (there being two anterior spiracles) of the larva is placed on the top of a small chitinous tube—the anterior larval

* For posterior spiracles of aphidiphagous larvæ see 'Syrphidæ of Ohio' by C. L. Metcalf, 1913.

respiratory cornu of an orange colour, which makes its way through the pupal skin and can be easily seen by the naked eye. The circlet of barbed bristles surrounding the posterior stigmata is not visible in the pupa.

The pupal respiratory cornua, which in addition to the anterior larval respiratory cornua help the pupa in respiration, and which can so very well be seen in the pupæ of its aquatic ancestors like those of the Eristalinæ, are absent. They are however present in the pupæ of *Eumerus aurifrons*, Wied., which were found at Pusa, buried in the muck of three-holes of *Siris* (*Albizzia lebbek*). Their absence in the pupæ of *Ceria eumenoides* is not without significance. Probably in nature the larvæ pupate on exposed surfaces and as such the absence of pupal respiratory cornua is justified.

The small fleshy processes of the ninth and tenth segments of the larva disappear in the pupa. The antennæ and the lips disappear. The parapodia are withdrawn, leaving behind them small patches on the ventral surface.

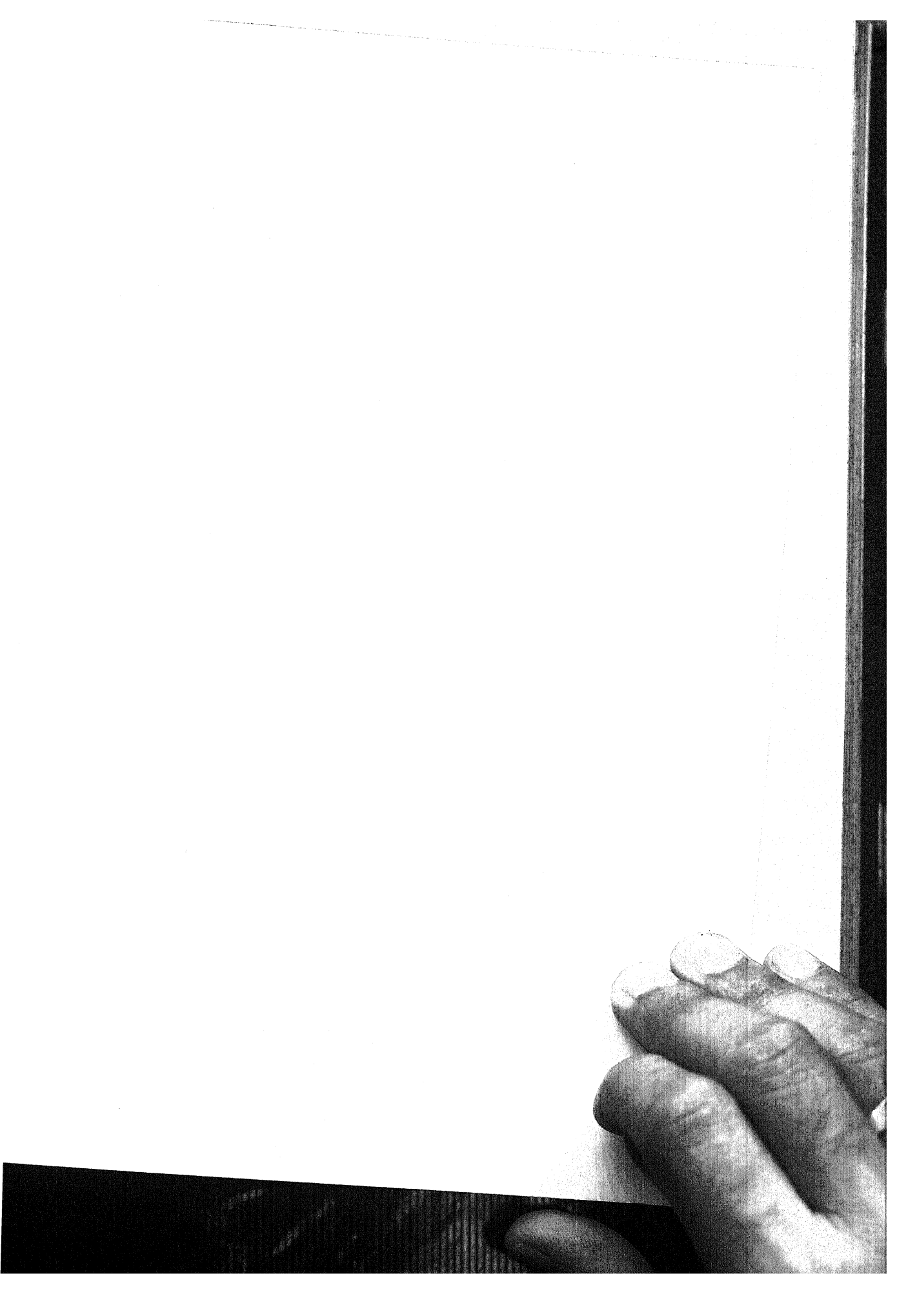
Life-Cycle.—The whole life-cycle lasts for sixteen weeks. The egg hatches in about forty-eight hours after it is laid. The larva feeds on the fermenting sap of *Siris* for thirteen weeks after which it pupates. The adult emerges fifteen days after the pupation of the larva.

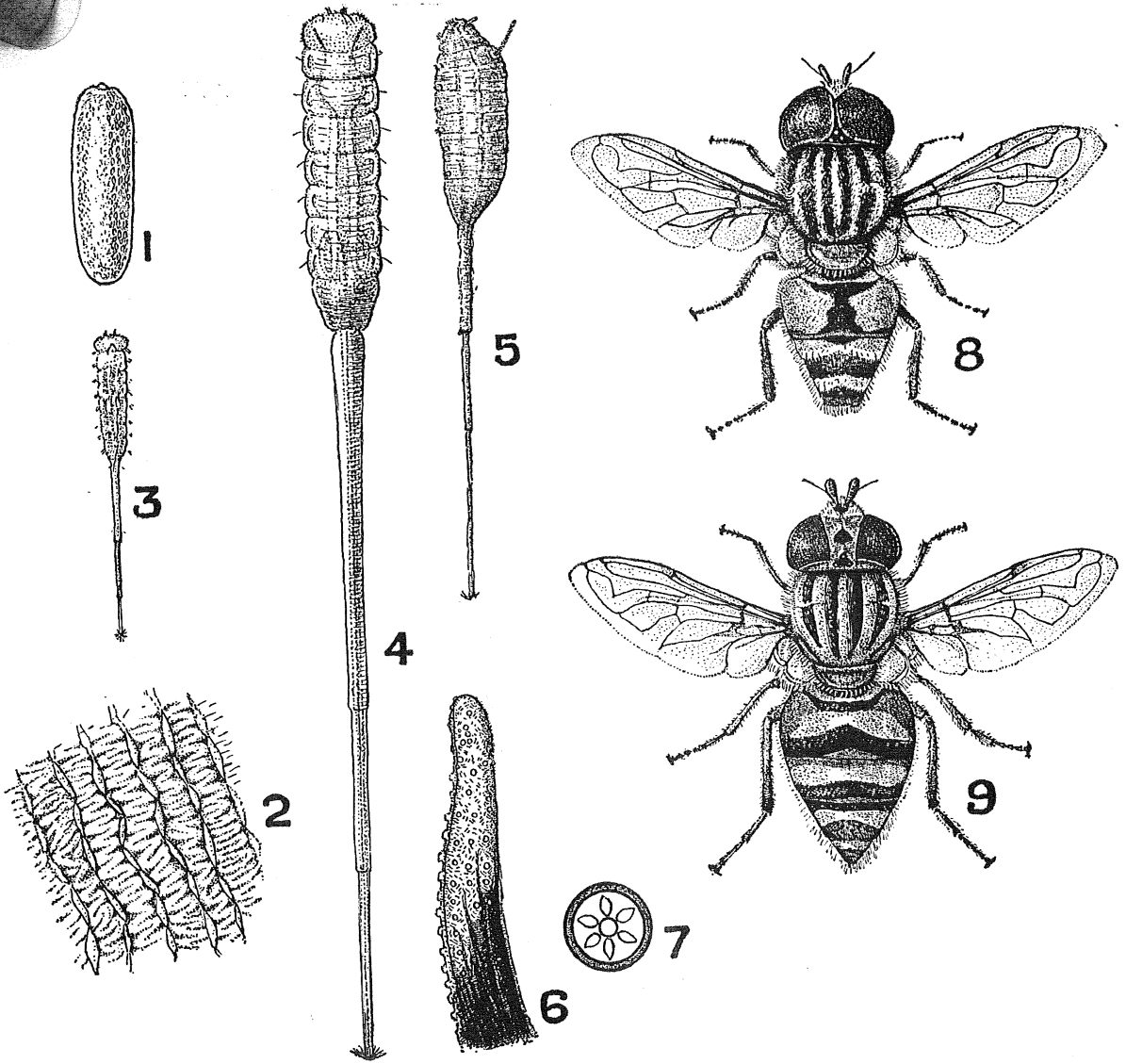
Life-history of E. quinquestriatus, Fabricius.

Introduction.

The "rat-tailed" larvæ of the various species of *Eristalis* are common practically all over the world. They are inhabitants of dirty drains and are known from very early times. G. B. Buckton [1895] has given an exhaustive account of practically all the stages of *Eristalis tenax*, Linn. Since then there have been some more contributions to the knowledge of pre-imaginal stages of other species of *Eristalis*. The present account is of the life history of *E. quinquestriatus*, Fabr., which has been reported in India from Kousanie, Kumaon District; Katmandu, Nepal; Sukna, base of Darjiling, Himalayas; Calcutta; Jubbulpore; Bangalore and Madhupur, Bengal. It is also common in Pusa.

The larvæ of *E. quinquestriatus* were observed in large numbers floating in every dirty drain during the last week of April and the whole of the month of May 1930 at Pusa. Adult flies were also actively hovering over the refuse in the drain looking for a suitable place for ovipositing. The eggs were seen laid in the moist soil on the sides of the drain or on the underside of rotten leaves and twigs seen in the shallow water of the drain. The fly took about ten minutes to lay a mass of 300 to 350 eggs. Oviposition in *E. quinquestriatus* was again observed in the beginning of August.





ERISTALIS QUINQUESTRIATUS, FABRICIUS.

1, The egg × 24; 2, Chorion of the egg highly magnified; 3, Young larva × 6; 4, Full-grown larva × 3; 5, Side view of the pupa × 3; 6, The pupal respiratory cornua × 36; 7, A small spiracle of the pupal respiratory cornua highly magnified; 8, Adult fly, male × $4\frac{1}{2}$; 9, Adult fly, female × $4\frac{1}{2}$.

Life-Cycle.—The whole life-cycle of *E. quinquestriatus*, Fabr., occupies twenty days. The eggs hatch within twenty-four hours. The larvæ, if properly fed, pupate after ten or twelve days, and a week later the adult emerges.

The Egg (Plate LVII, fig. 1).—Freshly-laid eggs are white, elongated oval in outline and truncated at the micropylar end. The chorion is sculptured with longitudinal rows of ovoid areas, each one with radiating arm-like, unbranched projections, extending into the spaces between the adjoining areas.

Food of the larva.—The young larvæ were kept in drain water, in small shallow glass dishes. Small, freshly killed fly maggots, collected from cow-dung, were found suitable as food for the young larvæ. The food was changed on alternate days. As the larvæ grew in size they were transferred to bigger glass dishes. The full-grown larvæ were found greedily devouring the fly maggots supplied to them as food.

Adult Larva (Plate LVII, fig. 4).—The body of the full-grown larva of *E. quinquestriatus* is 15 mm. long, 3·5 to 4 mm. broad and 3 mm. high. The tail is 35 to 40 mm. in length when fully extended. The colour of the larva is light grey.

The head bears sensory spines on its anterior margin. The antennæ arise below the anterior margin. Each antenna is bifurcated sub-apically, the inner bifurcation composed of two segments. The oral aperture, which is ventral in position, is guarded by a pair of lips, which by the aid of muscles cause a widening of the aperture thereby drawing in a current of water along with the organisms on which the larva preys. The lips have short, thick, conical spines on them.

Within the lips is found a hood-like chitinous termination of the œsophageal framework, which can be easily seen in a mounted specimen of the larva. Contained within the frame work are a number of black, chitinized, hard structures, homologous to the external mouth parts of the aphidophagous larva.

The tracheæ form a pair of chitinous white tubes opening anteriorly by the anterior spiracles, situated on the summit of the anterior larval respiratory cornua, which, in the full-grown larva, are seen protruding laterally at the junction of the head and the thorax. The tracheal trunks are united in the anterior regions by a transverse loop. The posterior stigmata are placed at the end of the long tail, which is a highly specialized organ, enabling the larva to feed at various depths without coming to the surface for respiration. The tail, which is concolorous with the body, is composed of three segments of different diameter, the basal one, which is a continuation of the last body segment, longer than the following two segments. The last segment, which bears the posterior stigmata, is armed with six barbed bristles ; it can be telescoped within the second segment.

The number of segments in the body is rather indistinct. Dorsally the body is segmented into groups of folds. On the ventral side there are six pairs of parapodia. Behind the segment bearing the last pair of parapodia, there is a clear segment bearing the anus, and before the segment bearing the first pair of prolegs, there is the prothoracic segment in front of which is the head consisting apparently of two segments. Thus in all there are ten segments excluding the tail, and if we suppose two segments for the tail, (the basal segment of the tail being only a continuation of the last body segment need not be counted as a segment), the number of segments in the body of *Eristalis* larva comes to twelve.

The anus, as mentioned above, is situated on the ventral side of the tenth segment at the base of the tail. It is provided with ten long digitate processes, which are extensile along with the muscular action of the body. Their function seems to be renal and this view is supported by Buckton [1895].

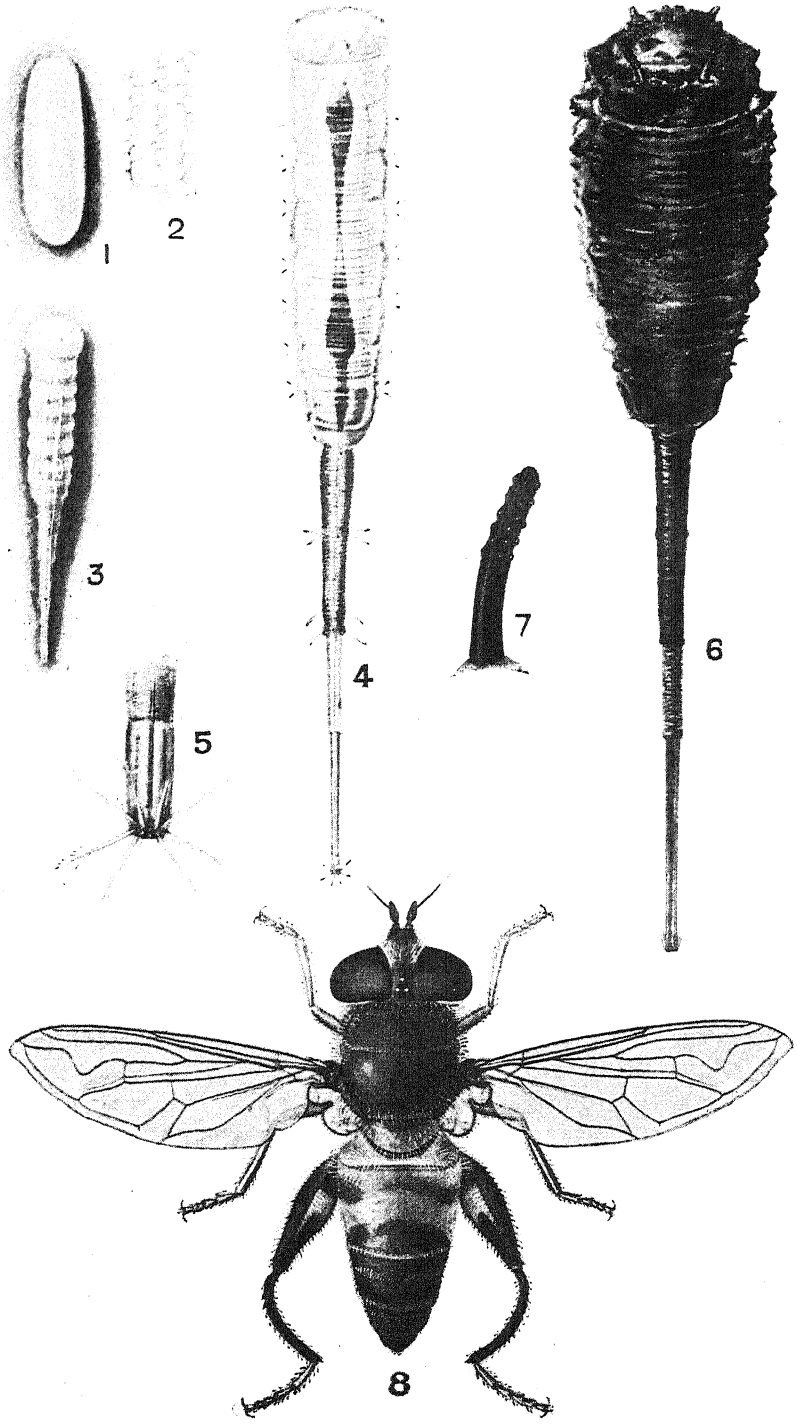
Pupa (Plate LVII, fig. 5).—The larvæ when fullgrown become very sluggish and stick to the glass cage and simulate death. They try to avoid water and prefer going towards slightly moist and soft soil where they find a suitable place to pupate. The maggot retracts its legs and lips, the soft skin of the larva becomes tough, the anterior larval spiracular cornua stand out of the larval skin and thus, with these preliminary changes, the larva pupates.

The pupa is 9·5 mm. long, 3·5 mm. broad and 3·2 mm. high ; the tail being 18 mm. It is yellowish-brown in colour, with a convex and wrinkled dorsal and a flat ventral surface, much the same as in larval stage, Ventrally six pairs of parapodia appear as shown by their recurved spines. Dorsally the surface slopes from the fourth segment towards the anal end. The two anterior larval respiratory cornua appear at the junction of the second and third segments. Each one is dirty yellow measuring 0·7 mm. The two black pupal respiratory cornua (Fig. 6), each 2 mm. long, are situated a segment behind the anterior larval respiratory cornua. The whole of the surface of each cornu is studded with small tubercles, each one representing a small spiracle through which the exchange of gases takes place.

The anus, together with the digitate papillæ, is well seen on the ventral side at the base of the tail. The bristles on the posterior spiracles at the tail end disappear.

Life-History of Helophilus curvigaster, Macquart.

Helophilus curvigaster, Macq., described in *Dipt. Exot.* II, ii. p. 62, Pl. 11, fig. 1. (1842), and by de Meijere, *Bijd. tot. Dierk.*, p. 99 (1904) and in *Tijds., Entom. LI*, p. 232 (1908), was collected at Darjiling in 1904. Since then it has hardly been recorded from any other locality. At Pusa the fly is seen during the beginning of August and it was only recently that its life-history was worked out.



HELOPHILUS CURVIGASTER, MACQUART.

1, The egg × 26 ; 2, Chorion of the egg highly magnified ; 3, Young larva ×14 ; 4, Adult larva × 4 ; 5, Terminal portion of respiratory tube highly magnified ; 6, Pupa ×6 ; 7, Pupal respiratory cornu × 24 ; 8, Adult female Fly ×6.

Oviposition.—For oviposition the fly prefers to oviposit in tree-holes full of decomposing vegetable matter. A gravid female was twice observed to enter the tree-hole and lay eggs. The process of egg-laying occupies from about ten to twenty minutes. The eggs are laid in a mass, but owing to the presence of some watery fermenting fluid it splits up into small masses. The small masses were collected during the first week of August and brought to the laboratory for rearing.

Life-Cycle.—The whole life-cycle occupies about five weeks. The eggs hatch from about twenty-four to thirty-six hours after they are laid. The larvæ grow for about twenty-five days after which they pupate. For pupation the larvae prefer moist saw-dust to moist soil. The pupal stage lasts for about eight days after which the fly comes out.

The egg (Plate LVIII, fig. 1).—Freshly-laid eggs are creamy-white with a light orange tinge, small, each measuring 1 mm. in length and 0·33 mm. in breadth. The egg is rounded at both ends with a micropylar knob at one end. The chorion is finely sculptured all over, by rows of small linear areas, each one supplied with a long chitinous marking branching in a spiral manner, the branches bifurcating at their ends.

Food of the Larva.—For rearing, small petri dishes were used. These were filled with the muck from which the eggs were collected. But it was found that the larvae failed to thrive in the medium. They were then kept in a medium consisting of the fermented exudation from a diseased tree and freshly-killed fly-maggots. In this medium they throve and the larvae were observed to devour the maggots with avidity and to grow, so much so that after twenty-four hours there was a marked increase in their size. They were kept on this food till they had become full-grown.

Young Larva (Plate LVIII, fig. 3).—The body of the larva much resembles that of *Eristalis*. The tail is white and longer than the body. Colour of the larva pale yellow. The first segment of the tail is very long, second shorter than the first, and the last still shorter and darker. At the end the tail is provided with eight barbed bristles. The tracheae opening at the end of the tail by the posterior stigmata are continued forwards showing a backward bend in the posterior third of the body. Anteriorly they show an inward bend between the third and the fourth segments and break up into capillaries supplying the head and the mouth parts. The anterior spiracles at which the tracheae open are prominent in the young larva, which, at the time of description, measured about 3·75 mm. in length and 0·5 mm. in breadth.

Full-grown Larva (Plate LVIII, fig. 4).—The adult larva is 15 mm. in length, 3·75 mm. in breadth, the tail being 30 mm. The body of the larva, as in *Eristalis*,

is convex dorsally, flat ventrally, the flat ventral surface forming a sort of creeping sole which is useful to the larva in crawling through the fermenting wood in which the larva lives. The dorsal surface is differentiated from the ventral one by a groove laterally. The body and the tail are marked by bifid hairs on the sides. The mouth, guarded by a pair of lips, provided with brown recurved spines, is situated on the antero-ventral aspect of the head, which is followed by a legless prothoracic segment. The anus, situated at the base of the tail, is provided with ten digitate processes, just as in the larva of *Eristalis*. The soft skin of the body is wrinkled and hence the number of segments of which the body is composed is not distinct. Ventrally there are six pairs of prolegs following the prothoracic segment, each provided with brownish recurved spines. Counting six segments for the six pairs of prolegs, one for the segment following the last pair of prolegs bearing the anus, another for the prothoracic segment, two for the head and two for the tail, the total number comes to twelve as in *Eristalis* larva from which it differs in colour of the body and the last segment of the tail.

The body is of a light brown colour ; the first segment of the tail, which is a continuation of the last body-segment, is also of a light brown colour, the second lighter except at times when the last segment of the tail is telescoped within it, in which case it is black within and pale brown outside. The last segment of the tail is black (not so in the larva of *Eristalis*), the tip light brown and armed with eight pale-yellow barbed bristles. It is the black colour of the tracheal tubes contained within the last segment of the tail that accounts for the black colour of this segment. The light-brown anterior larval respiratory cornu is seen through the translucent skin.

Pupa (Plate LVIII, fig. 6).—The larva, after feeding on decaying wood for twenty-five days, readily pupates in moist saw-dust. The pupa is 22·5 mm. in length, 5 mm. in breadth, and 4 mm. in height. The tail is 12 mm. long. The dorsal surface of the pupa is more convex than that of the larva and is of a chocolate colour tinged at places with orange. The ventral surface, flattened as in the larva, is light yellowish-orange. The body is marked on each side by a double row of small tubercles, the two rows separated by a depression on the surface on each side. The dorsal surface is wrinkled and on the fourth segment, at about one-fifth the length of the body from the anterior end, there is a crest, on both sides of which the body slopes towards the two ends. The pupal respiratory cornua, which first make their appearance as a pair of small processes forty-eight hours after the larva has pupated, are situated at about this place ; they are black, cylindrical, hollow, chitinous rods, each one millimeter in length ; the basal half of each is glossy and devoid of spiracles, the rest ornamented with small tubercles each bearing a small spiracle as shown in fig. 7.

Adult Fly.—The description of the female of *Helophilus curvigaster*, Macq., recorded in the *Fauna of British India* Brunetti (1923), is in fact that of the male and hence a description of the female fly is necessary.

Head.—Eyes bare, more widely separated below than at the top. Vertex black with black hairs. Frons and face shining black with yellowish dust at the sides above and white pubescence below. Tubercle black, not very prominent. Antennæ brownish black, arista tawny, tip black.

Thorax.—Dorsum black, the transverse band of grey pubescence only becomes distinct four hours after the adult emerges from the pupa case. Scutellum testaceous with fine white hairs fringing the margin.

Abdomen.—Curved underneath towards the tip, ground colour of the first four segments light brown, second, third and fourth segments, each with two black transverse bands, one at the base and the other at the posterior border, the bands united except in the first segment; fifth segment black.

Legs.—Fore and mid femora light brown, distal portions black above, hind femora orange, incrassated, distal portion with a black ring just before the middle; a black basal spot on the inner side of all the femora a large light brown obtuse prominence at the base of the hind femur; tibiæ black, the hind tibiæ curved and truncated at the distal end; tarsi light brown, pulvilli light yellow, claws black.

Wings.—Clear; a light yellow streak between the auxiliary and subcostal veins.

Lengths.—11 mm.; of wing, 8 mm.

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ABSTRACTS

Annual report of the Hmawbi Agricultural Station for the year ended 31st March 1930.

(*1*) *Fish-manure on paddy.*—The results of an experiment commenced in 1925 and concluded this year show that although a considerable increase in grain can be obtained, no monetary profit accrues. There is a strong residual effect, and even this year, the fourth residual, the largest application (30 lbs. N) showed a significant increase of 12·7 per cent.

(*2*) *Bone-meal on paddy.*—The results of an experiment commenced in 1924 and concluded this year, to test the efficacy of bone-meal in conjunction with ammonium sulphate applied that year, show that although a considerable increase in grain can be obtained no monetary profit accrues, the phosphate in the bone-meal being too slow acting. The residual effect appeared to be exhausted in this, the fifth residual year.

(*3*) *Basic slag on paddy.*—The results of an experiment commenced in 1924 and concluded this year, to test the efficacy of basic slag in conjunction with ammonium sulphate applied in that year, show that although a considerable increase in grain can be obtained no monetary profit accrues, the phosphate in the basic slag being too slow acting. The residual effect appeared to be exhausted in this, the fifth residual year.

(*4*) *Potash on paddy.*—The results of an experiment commenced in 1927 and concluded this year (1931) prove conclusively that the addition of potassium sulphate to a compound ammonium-phosphatic fertiliser gives no increase in yield. This is the general experience in Burma on paddy soils.

(*5*) *Residual effect of fertilisers on paddy.*—Several experiments with compound ammonium-phosphatic fertilisers indicate that, for the lower applications up to 100 lbs., the residual effect is exhausted in the second residual year, while applications of 200 and 300 lbs. continue to show considerable effect even in the third residual year. Again, the phosphatic content of the fertiliser largely determines the residual effect but economically it is found that the fertilisers with the larger proportion of N to P_2O_5 (*e.g.*, 20-20 grades) giving a more immediate return are more likely to be profitable to cultivators and that at the lower rates of application (*e.g.*, 50—100 lbs. per acre). [H. F. R.].

Annual report of the Myaungmya Agricultural Station for the year ended 31st March 1930.

(*6*) *Residual effect of fertilisers on paddy.*—Ammophos 20-20 and Diammonphos 20-53 applied at the rate of 100 lbs. per acre in previous year show an insignificant increase and a significant increase of 16·3 per cent. respectively in first residual year. This is more or less in agreement with results obtained elsewhere and confirms the belief that it is the phosphatic content of the fertiliser which largely determines the residual effect. [H. F. R.].

Annual report of the Mahlaing Agricultural Station for the year ended 31st March 1930.

(*7*) *Groundnut Spacing Trials.*—As a result of four years' tests it has been concluded that the optimum spacing for (1) Erect and (2) Spreading Varieties are respectively (1) 18″ between the drills and (2) 24″ between rows and 18″ in the rows. [H. F. R.].

Preparatory Tillage—A review of experiments in the Bombay Presidency.

H. M. DESAI. *Poona Agric. Coll. Mag.* 22, 127-135 (1930).

With a brief description of the soils, the crops and the methods of the preparatory tillage in common vogue in each of the distinct divisions of the Bombay Presidency, the results of any experimental work carried out in each division are summarised. They generally indicate that attempts at better preparatory tillage (*i.e.*, deeper stirring or exposing the soil in the hot weather or its inversion obtainable by deeper penetrating or inverting ploughs) than that secured by the common methods of harrowing or shallow non-inverting ploughs, have not given much benefit, except in localities in which the amount of rainfall and its distribution are indifferent. The conclusions drawn by the author from his review of his data contain the following note-worthy points :—

(1) The quality of tillage varies inversely as the amount and distribution of rainfall.

(2) The bullock power available, in the tracts of the Bombay Presidency, in which the amount and distribution of rainfall indicate an advantage for better tillage, has however greatly limited the practicability of the latter [V. G. G.]

Consumption of gul and sugar in rural and urban areas.

D. L. SAHASRABUDHE. *Poona Agric. Coll. Mag.* 22, No. 2 (1930).

It is observed that during the last 30 years the consumption of sugar is on the increase. In order to ascertain the likely cause, an enquiry was made in Poona and its surrounding villages to find out the quantities of gul and sugar consumed by people in the rural areas and by the various classes in the city. Figures for 9 villages were collected. The total population of these is 11,025. Their annual consumption of gul is 65,100 pounds or 5·6 pounds per head, while their consumption of sugar is 73,910 pounds or 6·4 pounds per head. The proportion of gul to sugar is 1 : 1·14. Figures for the city were obtained from families of varying standards of life and from boarding houses for boys and girls of the middle and poor classes. Only in the case of a few rich families gul has been displaced by sugar. Where tea is not consumed the quantity of sugar is only one-third that of gul. The quantity of gul used per head varies from 12 to 24 pounds per year. The quantity of sugar used by tea-taking population varies from 21 to 57 pounds per head per year. Their proportion of gul to sugar varies from 1: 1·6 to 1 : 3·4. [G. L. S.].

The wheat species : A critique.

A. E. WATKINS. *Jour. of Genetics.* 23, No. 2, pp. 173-263 (1930).

The author gives a critical review of the origin, variations and genetic relationship of the wheat species, and of their behaviour when crossed. The differentiation of the species into three distinct groups, characterised by 14, 28 and 42 chromosome number is first discussed and it is pointed out that there is a definite association between the chromosome number of a wheat plant and its characters. The range of variation within each group is dealt with and it is stated that most characters vary in similar fashion within both the second (28 chromosome) and third (42 chromosome) groups—a point well exemplified by Vavilov's " Law of Homologous Series in Variation ". The author sums up by saying that the wheat species fall into three clearly defined groups, each with a different chromosome number and that the chromosome number of any wheat form can be told from inspection. But though it is difficult to find any one character by which the 2nd and 3rd group, in particular, can be distinguished, separation is possible by the fact that some characters are found only in certain forms of one or the other group ; secondly, that though some characters vary within both groups, the two extremes of variation are either entirely confined to or are found most often in, different groups and lastly, that the way in which characters are combined may be different.

The division of the three groups into species is next discussed. The first group contains only two species of which monococcum is considered to be the most primitive cultivated wheat. In passing

from the species of the first to the second group, a number of new characters appear and with them a much greater diversity. The species of the 2nd group are connected with one another by transitional forms and when crossed with one another give fully fertile hybrids. The species of the 3rd group are easily defined and there is no disagreement as to their limits Differences between them are small and when crossed they give fully fertile hybrids, apparently showing simple Mendelian segregation.

The possible effects of natural crossing and selection in evolution and geographical distribution of wheat are considered at some length and the origin of the genus is discussed from the standpoint of three modern theories : Percival's (1921) theory, founded on systematic data, (2) Vavilov's conclusion (1926) from his work on geographical distribution, (3) Winge's (1917) theory of the origin of polyploid series. The author considers it very striking that different centres should have been found for the 14, 28 and 42 chromosome forms and alludes to the probability of the origin of *T. vulgare* by doubling of the chromosome number in a hybrid between Aegilops and one of the Emmer wheats.

It is pointed out that except in the case of the first group with the other two, all wheats can be crossed easily, giving fertile hybrids if they are of the same chromosome number and a partially sterile hybrid if they differ in this respect. Description of the nuclear behaviour (with figures) is given for crosses of the 42×28 chromosome wheats in which a regular number of 14 bivalents and 7 univalents appear ; for crosses of the 28 × 14 chromosome wheats in which the number of bivalents found is variable and usually less than 7, and for crosses of the 42 × 14 chromosome wheats with 0-5 bivalents. The cytology and significance of the various Aegilops and Triticum hybrids is discussed in some detail.

Chromosome behaviour and sterility in pentaploid wheat hybrids are next discussed and a reference is made to the various factors of sterility which influence the loss of the intermediate chromosome numbers, *viz.*, grain germination and the effect of extra chromosomes on the endosperm, failure to set grain through the egg-cells failing to become fertilised by their own pollen, egg-cells becoming non-functional, the abortion of the embryo, elimination of zygotes, pollen sterility with elimination of grains with chromosome numbers below 21, a possible loss of univalents at reduction in the female than occurs in the male, and irregular segregation of univalents in the female.

The association of chromosome number with single characters and the association between chromosome number and the way in which characters are combined in the pentaploid wheat hybrids are considered in detail. The danger of errors, unless the greatest care is taken over classification, is pointed out in working out the inheritance of types rather than of single characters in species crosses. The results of inheritance study in a number of species crosses are given and it is concluded that (1) some characters, such as hollow straw and resistance, are usually associated with a high or low chromosome number while others are easily transferred from one species to another ; (2) new characters appear, and there is a general tendency for variation to exceed the limits set by the parents ; (3) many characters segregate in linked groups—these groups are probably determined by groups of factors ; (4) there is a definite association between chromosome number and type, *i.e.*, combination of characters. All these facts evidently agree with the view that the tetraploid and hexaploid series carry respectively 2 and 3 similar series of factors. The speltoid mutants are discussed in relation to Winge's theory that they arise from the irregular pairing of chromosomes at reduction ; thus giving a rearrangement of the existing genetical material, gametes ABB and ACC being produced instead of ABC, with the subsequent formation of 41, 42 and 43 chromosome forms. Reference is made in this connection to Nilsson-Ehle's theory of factor mutation and to the valuable data by Lindhard (1922, 1923).

In the study of inheritance in crosses between tetraploid wheats, the phenomenon of 'shift' is discussed with reference to Darlington's (1921) explanation that autosyndesis occurs in connection with some of the chromosomes carrying modifying factors, and Malinowski's (1926) explanation of linkage between two chromosomes.

The cumulative factor theory of Nilsson-Ehle is next considered and it is pointed out that it is specially applicable in the case of hexaploid species.

In the concluding remarks, it is pointed out that hybridisation is the most plausible explanation for the origin of the tetraploid and hexaploid wheats. In the origin of hexaploids, from a cross between a tetraploid wheat and *Aegilops ovata* or *A. cylindrica*, certain difficulties are pointed out. Reference is made to the effect of recombination of characters followed by selection on the origin of variations within the group. There is good ground for supposing that many features of the genus are the outcome of its polyploid nature. (D. N. M)

Perennial Rye-Grass Strain Investigation. Single-plant trials at the Plant Research Station, Palmerston North. E. B. LEVY and W. DAVIES. *New Zealand Jour. of Agric.* 41, No. 3, pp. 147-163.

Perennial rye-grass shows variation in growth-form from very lax and spindly to very dense and bushy. The latter produce more leafy growth and give a much higher total yield spread out over a longer growing season, and are, therefore, more suitable for pastures.

The method followed for the improvement of this grass consists of a three-fold test—the broadcast plot, spaced plant trials of single plan plants and the final test in the field under ordinary conditions.

The present article deals with the second phase of the trials, *viz.*, the single-plant study.

The whole of the lines sown out in the broadcast were classified according to type defined by eye-differences in the seedling stages. From the chosen lines, single plants were dug up at random and planted out as spaced plants in rows 2 ft. apart in the row and 2 ft. between each row. Five rows of 20 single plants per row constituted a plot of each line under test. A known type of English indigenous rye-grass, planted between every other plot contiguous to each line, was used as a control in these experiments.

These trials showed that eye differences in the broadcast were essentially due to differences in the nature of the individuals that made up that line and that not only do the individuals vary between lot and lot, but marked variation exists among the individuals of any one single lot. In the one lot the type may be dominantly true perennial, true Italian or false perennial.

The single plant analysis emphasizes the mixed nature of the ordinary New Zealand commercial types that exist to-day—a variety of growth-forms being observed in each. This study also shows the marked state of deterioration that New Zealand commercial rye-grass has come to by years of haphazard, unguided seed production. As a result of continuous reaping and sowing, the leafy shy-seeding true perennials are in danger of being suppressed.

The ideal growth-form for conditions in New Zealand, should be like the fine-leaved, dense-crowned, multi-tillered form observed in the single-plant study of a Hawke's Bay line (Type 1). It is obvious, however, that from the mixed material, it would be a hopeless task to try to breed up to anything approaching genetic purity and that, therefore, it is better to go straight to the Hawke's Bay product and start on material that at least has not undergone hybridization and deterioration to the extent of commercial rye-grass from the South.

The English indigenous type used as control in these experiments, also showed variations in growth-forms and flowering—indicating that perennial rye-grass even from old-established swards may contain many undesirable types that have to be eliminated in elite-strain building.

The single-plant studies have definitely shown that there is a very direct relation between the density of the plant and its ability to withstand repeated defoliation. They have also demonstrated that the dense leafy types are much more resistant to disease than the stalky open-crowned forms.

This means that in the breeding of pasture-plants, one may be able to employ simple diagnostic characters in the selection of forms of greater economic value to serve as parent material in the production of improved and elite strains.

In economic grassland production, therefore, the importance of strains within the species, must not be lost sight of. (D. N. M.).

The use of selfed seed in maintaining the purity of improved cottons.—G. L. KOTTUR. *Agric. J. India* **25**, pp. 39-41.

The author describes the system whereby the pure cottons "Dharwar I" (an improved Kumpta cotton) and "Gadag I" (an improved Dharwar-American cotton) are spread in a pure state over 200,000 acres. The plant-breeder produces the original supply of pure seed economically by fixing wire rings on the buds to be selfed. One woman can self 1,000 buds in one morning. From this selfed seed 6,000 to 9,000 lbs. pure seed is raised on the Dharwar Government Farm and is then distributed to selected growers for further multiplication. This seed is collected and ginned under departmental supervision and cotton sale societies take care of its sale. The department rogues the fields, and the number of rogues is more than 6 per cent. (W. B.)

Influence of bagging on oil percentage in castor. G. B. PATWARDHAN. *Poona Agric. Coll. Mag.* **22** (1913).

47 samples of seed from bagged inflorescences were compared by analysis for oil-content against 47 samples from unbagged inflorescences (each bagged sample against the unbagged one from the same tree) and the results treated statistically. The result is that bagging does not significantly affect the oil-co. (W. B.)

Relation of bloom on castor leaves with Jassid attack. G. B. PATWARDHAN. *Poona Agric. Coll. Mag.* **22**, 14-15.

Observations of 1,000 castor plants in one season indicate that bloom is a protection against Jassids (*Empoasca flavescens*). (W. B.)

The grain-shedding character in rice plants and its importance. S. G. BHALERAO. *Agric. Res. Inst. Pusa., Bull.* No. 205 of 1930, pp. 1-36.

This is an account of a serious difficulty that besets rice-growers in the Belgaum, Dharwar and Kanara Districts of the Bombay Presidency. Wild rice grows freely round tanks and has the apparently primitive character of grain-shedding. The author confirms what was previously pointed out by Watt that this shedding is due to a mechanically feeble arrangement for attaching the grain to the rachilla. This character is apparently hereditary and can be transferred to cultivated rices by crossing, and this has already happened to such an extent that cultivators have coined the term *gonag* for rices growing in cultivation and simulating cultivated rice, but possessing this evil quality. The author records the progeny for three generations of such *gonags* and shows that they split for several characters, including grain shedding, and that non-shedding types can be isolated from them.

The author does not appear to have actually made any crosses between wild and cultivated rice.

As methods of control the author recommends the destruction of wild rice in tanks and modifications in cultivation such as rotations or transplanting (the rice on the area being all drilled), and the provision of a pure seed supply. (W. B.)

Production of alcohol from the spent mohwra Bassia latifolia flowers. D. L. SAHASRABUDHE and V. G. PATWARDHAN. *Poona Agric. Coll. Mag.* **22**, No. 1, July 1930.

Mohwra flowers are used in large quantities in several Indian distilleries and the spent flowers are generally thrown away as a waste. One of the experiments tried by the authors was to convert the carbohydrates of the spent flowers into fermentable sugars for the production of alcohol.

The spent flowers were subjected to various treatments and the extracts were fermented at Khanapur (Belgaum District) in the Government Distillery. As a final result it was found that when the spent Mohwra flowers are heated under three atmospheric pressures for four hours with twentieth normal sulphuric acid and pressed, the extract obtained contains fermentable sugars. This extract though acid need not be neutralised. It can be safely added to the usual saccharine extract from original flowers. The mixture ferments well and the yield of alcohol shows that all the sugars in the extract from the spent flowers are turned into alcohol. (D. L. S.)

Soils of the Bombay Presidency. D. L. SAHASRABUDHE. *Bombay Agric. Dept. Bull.* No. 160 (1929).

The soils of the Bombay Presidency as a whole are considered from the point of view of the geological formations and the climatological conditions. The nature of the constituents of the soils as shown by their chemical and mechanical analysis and their relation to crops are described in a general way. Alkali soils developed along the irrigation canals, *kari* or infertile soils of the Karnatic, *mânat* or sticky clayey soils of the north Konkan, *morik* or acid soils of the south Konkan are each separately dealt with. Soils are then considered district by district. Important and typical soils of each district are mentioned with their chemical and mechanical constituents. The analytical figures represent a very large number of samples of each type of soil. The details given include the extent of the area occupied by each soil, its geographical position, its fertility, relation to crops, etc. There are two maps given, one showing the rainfall and another showing the geological formations of the presidency. These two maps are very useful in understanding the situation and the exact conditions under which the different soils have been formed. (D. L. S.)

Cattle feeds of Western India. D. L. SAHASRABUDHE. *Bombay Agric. Dept. Bull.* No. 161 (1930).

Principles of cattle feeding are dealt with in a general way, discussing the relation of the food constituents to the body of the animal. This is followed by the discussion of the digestibility of the various types of foodstuffs, their quantities necessary for the cattle, importance of mixed proteids, vitamins, bulk of the food and so on. The bulletin is chiefly devoted to the concentrates used in the Bombay Presidency. They include oil-cakes, oil-seeds, grains, by-products of grains like the brans, husks, polish, etc., and also leaves, stems, and roots of special value. In each case variations in the composition as found in a large number of samples are given along with the composition of typical samples. The properties of the various cattle feeds are also discussed in short. At the end analytical figures are given for some of the important types of silages in the Bombay Presidency such as those from maize, jowar, sugar-cane tops and grasses. (D. L. S.)

Manufacture of lime juice and its economic value. V. H. KULKARNI. *Poona Agric. Coll. Mag.* 12, pp. 88-92 (1930).

Lime products valued at Rs. 14,000 were imported into India in 1929. The poor status of the lime industry is attributed to the growers' lack of knowledge of fruit preservation.

The preparation of lime products other than juice needs much capital and technical knowledge while the equipment required for preparing juice is simple costing Rs. 350, and can be made locally. It consists of :—

1. A simple lever press mounted on a stool.
2. Glass containers and crown bottles.
3. Felt bags.
4. Pasteurizer.

5. Bottle capping machine.
6. Thermometer.

The pressed out juice is clarified by natural sedimentation for 15 days, then syphoned out and further clarified by passing through felt bags. The previously sterilized bottles are then filled and capped. They are then placed in the pasteurizer for 30 minutes at 55° C. and later stored in a cool place.

Juice enough for 88, 12-oz. bottles is extracted per day at a cost of 6¾ annas a bottle which sells at 10 annas. A season's work brings a profit of Rs. 3,333. (G. B. P.)

The mango hoppers and mildew and their control. P. V. WAGLE. *Poona Agric. Coll. Mag.* **21**, pp. 170-173 (1929).

An account is given of the experiments in the control of mango mildew and jassid hoppers (*Indiocerus niveosparsus*, *I. clypealis*, and *I. atkinsoni*) made by the writer at Ratnagiri. Brief notes on the life-histories of the two pests are also given.

A number of fungicides and insecticides were tested; but the results on four (named) of them are discussed. Fish-oil-rosin soap proved ineffective against powdery mildew and hoppers. Bordeaux mixture 5-5-50 gave satisfactory results; but four to five applications were necessary for effective control. Sulphur dust alone and in combination with calcium cyanide "A" in the proportion of 6 parts of sulphur to 1 part of cyanide, gave the best results in control. Two applications of sulphur are necessary for effective control, the first application to be made just after flowering and the second a fortnight later. If, however, hoppers still appear on the dusted trees, a third application of sulphur-cyanide mixture (6—1) may be made. At a cost of Rs. 2 per tree for the treatment, a normal yield of mangoes can be secured, resulting in a net profit of Rs. 6 per dusted tree. (B. N. U.)

Powdery mildew of the grape and its control in Bombay. B. N. UPPAL, G. S. CHEEMA, and M. N. KAMAT. *Bombay Agric. Dept. Bull.* **163**, 1-30. (1930).

An account is given of the investigations into the phenological relations and control of *Uncinula necator* made by the authors in Bombay, from 1926 to 1930. Notes on the disease and the casual organism are also given.

The fungus can grow within a temperature range of 50 to 100°F., and in the atmospheric humidity of 40 to 95 per cent. Precipitation adversely affects the disease; cloudiness directly influences it.

Sulphur dust gave the most effective control of mildew; Bordeaux mixture and D. F. P. dust failed to do so. Sulphur did not scald or stain the fruit, and also hastened its ripening. Three applications were fully effective, and required from 75 to 85 pounds per acre. The cost of the treatment was Rs. 8-8-0 per acre. Crank dusters were more efficient than those of the bellows type. Adulteration of sulphur was tried with several (named) substances, and was not found to impair its effectiveness up to 20 per cent. of the weight of free sulphur in the mixture. In Bombay Bordeaux mixture spraying can be dispensed with during the fruiting season; but if vines are pruned out in September, one application in October will prove useful in checking anthracnose or downy mildew. (B. N. U.)

REVIEW

Maize in South Africa. By A. R. SAUNDERS. (South African Agricultural Series, Vol. 7.) Pp. 284+72 plates. (Johannesburg : Central News Agency, Ltd., 1931.) 21*s*. net.

This book is number seven of the South African Agricultural Series. These text-books seem to be well written and form an authoritative collection relating to agricultural conditions in South Africa, written by leading authorities in their respective subjects. The book is divided into 13 chapters as follows :—

1. History.
2. Statistics.
3. Climatic Conditions.
4. Botany of the Maize plant.
5. Soil.
6. Manuring.
7. Agricultural practices.
8. Varieties
9 & 10. Diseases.
11. Breeding problems.
12. Utilisation.
13. Commercial.

According to official statistics maize in India is a comparatively unimportant crop. There are only 3 provinces which cultivate more than a million acres. United Provinces and Bihar and Orissa altogether possess about two-thirds of the total area under the maize crop. Its importance, however, from a rural economic point of view is very much greater than the cultivated area would lead one to assume. It is very generally cultivated in small quantities where irrigation is available and the green cobs used as a vegetable. Much botanical work requires to be done on maize in India and the present text-book will be read with considerable interest by all concerned with agriculture as a general guide to this important crop.

The section on varieties is of particular interest and it is noted that the bulk of the crop in South Africa consists of white dent and yellow flint types. The flints are stronger and hardier but the dents seem to be more suitable for high temperatures. In India varieties from South Africa have in some cases proved more promising than introductions from the United States. Generally such introductions are found to mature later than the indigenous stock. The importance of maize as a silage crop is given due weight. Maize silage has revolutionised dairying practice in the United States of America and it will undoubtedly be a big factor in this country in the development of dairying.

The book is well illustrated and forms a most interesting and instructive Manual. The language is simple and clear and there is a very complete list of relevant literature on the subject. The succeeding volumes of this series will be observed with interest. If the standard of the present volume is maintained the series will be of considerable value to this country, where in some areas the soil and climatic conditions bear a resemblance to those of South Africa. (G. S. H.)

AWARD OF THE MAYNARD-GANGA RAM PRIZE.

In 1925 the late Sir Ganga Ram, Kt., C. I. E., M. V. O., R. B., Lahore, with that generosity for which he is now so well known, handed over to the Punjab Government a sum of Rs. 25,000 for the endowment of a prize of the value of Rs. 3,000 to be called the Maynard-Ganga Ram prize and to be awarded every three years, for a discovery, or an invention, or a new practical method which will tend to increase agricultural production in the Punjab on a paying basis. The competition is open to all throughout the world. Government servants are also eligible to compete for it.

Sixty-four entries were received in competition for the first award of this prize. Out of this number, however, only fourteen complied with the conditions of award. Four Committees of judges were appointed to examine and report on these entries. Their reports were considered finally by the Managing Committee of the prize on 3rd March, 1931, when it was decided that the prize should be awarded to Dr. C. A. Barber, Sc. D., C. I. E., 294, Cherryhinton Road, Cambridge, for his fundamental discoveries which have resulted in the production of Coimbatore seedling canes. These canes have been definitely proved to be much higher yielders under Punjab conditions than the old indigenous canes. The area under Coimbatore canes in the province is increasing rapidly each year and it is expected that they will totally replace indigenous varieties in a few years' time.

Applications for the next award should reach the Director of Agriculture, Punjab, Lahore, on or before the 31st December, 1932.

HUMBERT-MARIE JOSÉ PRIZE.

The following regulations for the grant of the Humbert-Marie José Prize have been approved by the Permanent Committee of Institute International d'Agriculture, Rome :—

1. An annual prize, which on account of the circumstances under which it was endowed, is to be known as Humbert-Marie José Prize, is instituted for the best work in Agricultural Economics—comprising all problems relating to Economics and Agricultural Statistics.

The prize consists of a gold medal and a sum of 10,000 lirahs and will be awarded by the Permanent Committee in all years, according to these regulations.

The date (of receipt of work) expires on the 30th September and the award will take place on the 31st December 1930.

2. The work of authors belonging to the countries adhering to the Institute

and published in the course of the preceding two years will be alone admitted to the competition.

3. If any work is published in many parts, then it is admitted as a whole, at the period in which the final part has been published.

4. A new edition of any work published previous to the period will not be admitted unless substantial changes or additions have been made.

5. Work carried out by any member of the Jury will not be admitted to the competition, nor any work which has already been submitted to any International Competition and for which the author has received any prize in cash.

6. At the close of each period the General Secretary of the Institute will invite the members of the Committee for Rural Economics and Statistics of the International Council for Scientific Agriculture of the Institute, as well as of the Committee of Agricultural Economics, to forward 6 copies of work carried out by their respective countrymen, which in their opinion deserve to be submitted to the International Jury, by reason of their scientific merit. He may, if necessary, point out any publications known to him which conform to the conditions of the competition.

The members of the International Council of Scientific Agriculture and of the Committee for Agricultural Economics who forward any work for the competition should also send with the copies of the work in all important cases, a brief report indicating the nature and contents of the work as well as their personal appreciation of its scientific character.

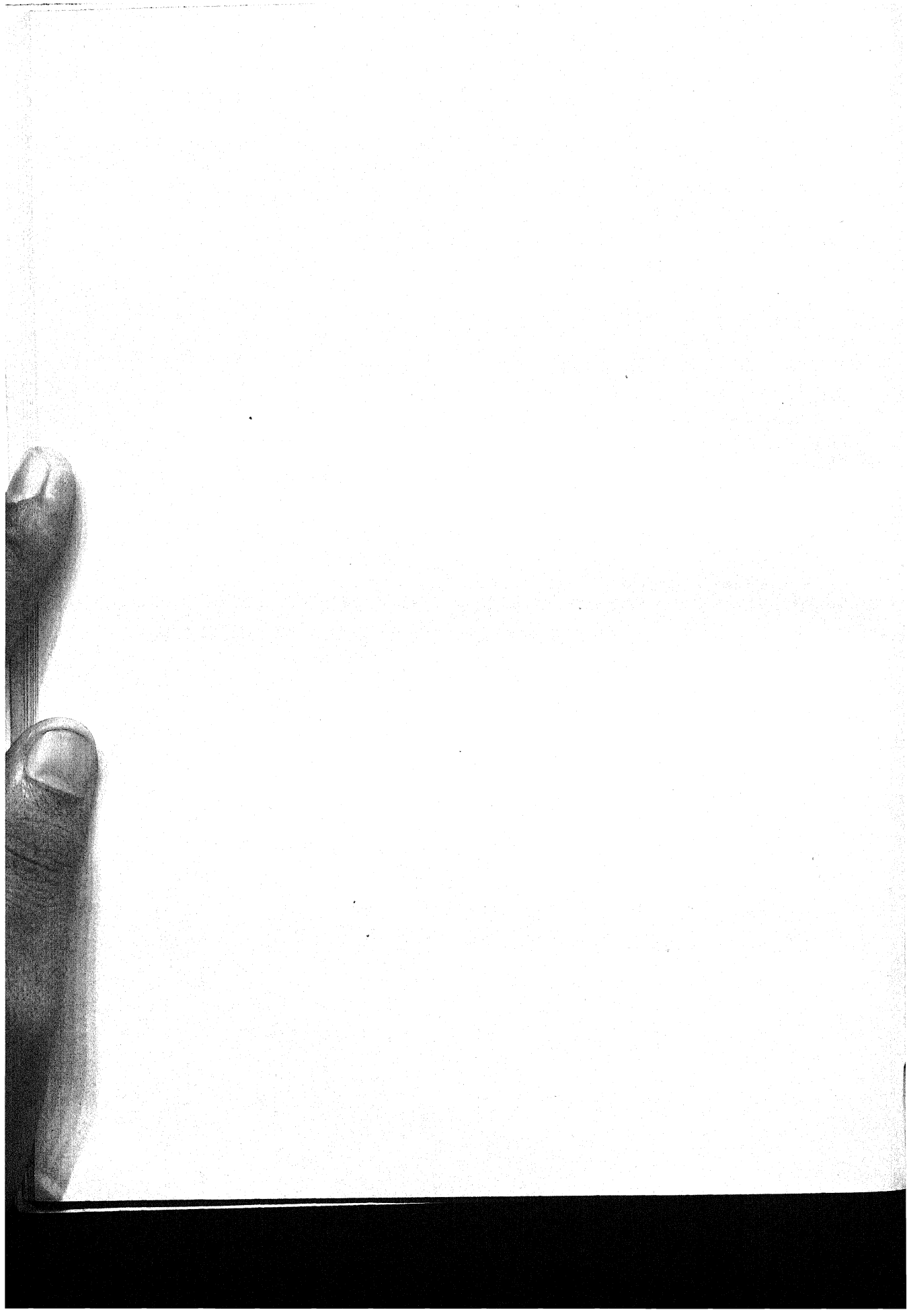
Works transmitted directly by the authors to the Institute will be sent by the General Secretary to a member of the competent Section of the International Council of Scientific Agriculture or of the Committee for Agricultural Economics for report as mentioned above.

7. The final judgment in the competition will be given by a Jury composed of 5 members consisting of the President of the Institute, and 4 members nominated from among the members of the International Council of Scientific Agriculture and the Committee for Agricultural Economics. The selection will be made in such a manner that the Jury will be composed of men belonging to 5 different nationalities. Each member of the Jury may have a substitute only of the same nationality.

8. A copy of all the works presented to the competition and of the reports accompanying them will be sent to each member of the Jury. The Jury cannot examine any other work besides those officially sent to them.

9. Each member of the Jury after examining the works will draw up his order of preference and transmit it to the General Secretary. If any work placed at the top obtains 3 votes, then the prize is awarded. If no work obtains 3 votes, the General Secretary will draw up a list composed of two works placed at the top of the list obtaining the greatest number of votes and send it to the members of the Jury for a fresh ballot. The result of the second voting will determine the prize.

N. B.—Expiry of the second period for the presentation of work: 30th September 1931; Grant of the Prize: 31st December 1931.



ORIGINAL ARTICLES

EFFECT OF MOSAIC ON THE TONNAGE AND THE JUICE OF SUGARCANE IN PUSA

BY

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(Received for publication on the 8th June 1931.)

In the literature on the mosaic disease of sugarcane there are numerous references to a great reduction of tonnage and to a small reduction of available sucrose due to this disease. In addition to those given by Sayer [1929] two typical examples may be quoted. Earle [1928] states that "In Porto Rico carefully compiled statistics of sugar production at all of the mills for the years 1917 to 1919, when divided into districts corresponding to the extent of infection, showed that in the non-infected eastern district production in 1919 was somewhat in excess of 1917. In the heavily infected western district, however, average yields had fallen forty per cent. below those of 1917. These losses could only be accounted for as due to the effect of the disease". And Freise [1930] states that "As far as investigations in Sao Paulo and Rio de Janeiro go, mosaic disease affects first the output of cane per acre of land; then, but, in much more moderate degree, the content of sucrose in the affected cane. While the output may go down as far as twenty-five per cent. of normal, the sucrose percentage decreases on the average only from 12·4 to 11·96 per cent. in cane of the variety Taquara, or from 12·9 to 11·3 per cent. in Riscada cane. The Cayanna variety shows a decrease from about 13·1 to 10·2 per cent.; this cane seems to be the most susceptible to mosaic". These losses occur in the noble canes infected with mosaic but with the exception of Hemja the thin canes of northern India that are infected with this disease do not show striking reductions of this kind in tonnage. Eye observation of the standing cane does not reveal any marked reduction though there is a belief in the mill that the available sucrose is reduced. Plots to indicate these points have been grown in Pusa for the last three years, but they did not show any marked difference in tonnage or in sucrose. During this time it was noticed that secondary infection was extremely small, thus conditions seemed to be favourable for a field experiment of a series of adjacent plots of mosaic and mosaic-free cane. In 1930, plots of Coimbatore seedling canes, Co. 213 and Co. 205, were laid down in Pusa so that

differences could be more accurately determined. Co. 213 is the cane that has found most favour in the white sugar tract of north Bihar and Co. 205 appeared to be a good cane for the poorer class of land.

Co. 213.

Twenty plots, each nine yards by fifty-four yards, were laid out in the order, mosaic, mosaic-free, mosaic-free, mosaic, the group of four being repeated five times. There were nine rows of cane in each plot.

North.

1. Mosaic	M
2. Mosaic-free	F
3. Mosaic-free	F
4. Mosaic	M

Repeated five times.

The area was good, even, heavy land suitable for growing sugarcane and its parts had been subject to the same rotation in previous years. The operations of planting and cultivating were carried out by Mr. Wynne Sayer, the Imperial Agriculturist, according to the usual practice on the farm. Superphosphate at the rate of one maund per acre was given before planting and castor-cake at the rate of ten maunds per acre at the time of planting. The variety of cane was Co. 213. Planting was eye to eye and the germination on all plots was good.

(*a*) *Mosaic cane* :—This cane was taken from plots wholly infected with the disease and sets were cut from canes whose leaves showed mosaic markings at the time of harvest. Thus this cane was definitely known to be mosaic infected.

(*b*) *Mosaic-free cane* :—The sets were cut from cane that from frequent observation during the growing season was known to be entirely free from mosaic disease, and at the time of harvest had no mosaic markings on the leaves. Thus the cane was definitely known to be mosaic-free when planted.

During the season 1930-31, a small amount of infection spread to the mosaic-free plots and twenty-three clumps were found to have the disease as follows :—

Plot Number.	2	3	6	7	10	11	14	15	18	19
No. of clumps with mosaic disease.	1	0	6	1	3	4	1	2	3	2

Found in May and June they were pegged and left in the plots, but subsequently no further cases were found. Of the twenty-three mosaic clumps seven were in

the parts of the plots cut out to eliminate edge effect. These numbers are too small to make any appreciable difference in the yield of the mosaic-free plots. They are a measure of the natural spread of the disease during the year in the conditions of the experiment and show that such spread was small. This is in consonance with the result of another experiment to test the spread of mosaic disease in the field. Here, in half an acre alternate rows of healthy cane of twenty-five varieties were grown with alternating rows of mosaic-infected Co. 205 cane, and during the year nine clumps became infected. It is this small rate of spread of the disease this year that has rendered the experiment practicable.

No damage was done by other cane diseases, and extremely little by borers and animals. The experiment was thus a good one for testing the difference between mosaic and mosaic-free cane.

A random sample of cane was taken for analysis from each plot. From each of the seven rows that were to be weighed finally in each plot three canes were taken at random. Numbers from 1 to 50 representing the number of yards in the final plot were placed in a basket and kept stirred. The numbers drawn represented the number of yards from the end of the row at which the canes were to be taken; the cane at the end of the measuring rod at the proper number was the one taken. Samples from five plots were taken and analysed each day from the 27th to the 30th January 1931, when the cane was considered to be ripe. The cane was crushed in a bullock-driven, three-roller, iron mill. The analyses were furnished by Dr. Harrison, the Imperial Agricultural Chemist. The details are as follows:—

Plot numbers		Weight of cane in lbs. from samples		Weight of juice extracted in lbs.		Percentage weight of juice to cane		Brix (corrected)		In juice					
										Sucrose per cent.		Glucose per cent.		Purity per cent.	
F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M
2	1	43·75	45·00	27 25	27·75	62·29	61·67	15·45	14·91	13·39	12 48	·589	·682	86·65	83·73
3	4	40·50	35·50	25·25	22·25	62·34	62·68	15·24	15·30	12·99	13·50	·690	·658	85·23	88·26
6	5	38·00	36·00	25·25	22	66·32	61·11	16·81	15·77	15·60	14·07	·453	·588	92·77	89·20
7	8	35·00	31·50	22	19	62·86	60·32	16·58	15·49	15·37	13·89	·419	·495	92·67	89·70
10	9	34·50	28·00	21	17·25	60·87	61·61	16·95	15·02	15·25	13·09	·384	·707	89·99	87·13
11	12	36·00	33·25	23	21·25	63·89	63·91	16·97	16·35	15·48	15·06	·452	·347	91·24	92·13
14	13	34·5	33·5	20·5	20·25	59·42	60·45	17·47	17·09	16·22	15·73	·369	·350	92·86	92·03
15	16	30·5	31·5	18·5	20	60·66	63·49	17·47	16·18	16·42	14·45	·315	·380	93·97	89·32
18	17	36	32	23·25	20·25	64·58	63·28	15·83	15·12	14·33	13·37	·599	·706	90·54	88·41
19	20	35	33·25	22·75	22·75	65	68·42	15·95	15·35	13·82	13·37	·722	·657	86·64	87·08
Mean.		36·375	33·95	22·875	21·275	62·823	62·665	16·472	15·658	14·887	13·901	·499	·557	90·256	88·699

At the time of harvest six feet of cane from the ends of the rows and the two outside rows were removed from each plot to eliminate edge effect. Thus there was left in each plot 7 rows of cane in an area 7 yards by 50 yards. The weights in maunds of stripped cane from the plots are as follows. One maund=82·28 pounds avordupois.

F	M	Mosaic-free	Mosaic
2	1	58·7	55·5
3	4	56·9	52·4
6	5	46·8	49·7
7	8	42·6	45·4
10	9	48·2	42·8
11	12	46·2	45·9
14	13	42·5	39·6
15	16	42·9	42·7
18	17	53·2	43·6
19	20	50	47·9
	Mean	48 86	46·55

Difference 2·2 mds. or 4·6 per cent.

Co. 205.

Eight plots, each eleven yards by forty-four yards, were planted alternately with mosaic-free cane and there were eleven rows in each plot. The area was light, high land rather lighter than is considered good for cane but it was the only site available seeing that the main cane area on the farm had to be protected from infection. The operations of planting and cultivating were carried out as in the former experiment. The mosaic and mosaic-free cane were chosen as before. On being examined during the season, the mosaic plots showed 97 per cent. infection and the mosaic-free plots 0·7 per cent. This latter amount is however too small to materially affect the result. No damage was done by other cane diseases and very little by borers and

animals. A sample of cane for analysis was taken from each plot on 26th and 27th February and the details are as follows :—

Plot numbers		Weight of cane in lbs. from samples		Weight of juice extracted in lbs.		Percentage weight of juice to cane		Brix (corrected)		In juice					
										Sucrose per cent.		Glucose per cent.		Purity per cent.	
F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M
1	2	18·18	16·80	9·60	10·10	52·81	60·36	18·48	18·16	16·26	15·92	0·44	0·56	88·01	87·64
4	3	17·70	16·50	9·60	9·90	54·24	60·00	18·49	17·86	16·12	15·52	0·55	0·52	87·20	86·88
5	6	16·68	16·62	8·70	9·10	52·16	54·51	18·10	18·41	16·05	15·96	0·67	0·76	88·69	86·74
8	7	13·80	16·26	7·70	8·40	55·80	51·67	18·10	18·57	15·79	16·48	0·56	0·67	87·21	88·76
9	10	15·60	12·00	9·30	5·90	59·62	49·17	18·33	18·75	15·92	16·27	0·52	0·58	86·83	86·79
12	11	12·70	13·50	7·10	8·10	55·91	60·00	18·10	18·57	15·71	16·36	0·51	0·58	86·81	88·11
13	14	15·00	14·40	9·00	8·50	60·00	59·03	18·65	18·24	16·53	15·92	0·60	0·47	88·64	87·26
16	15	13·00	17·20	7·30	9·90	56·15	57·56	17·48	18·01	15·25	15·44	0·46	0·50	87·26	85·76
Average		15·33	15·41	8·54	8·74	55·83	57·54	18·22	18·32	5·95	15·98	0·54	0·58	87·58	87·25

At the time of harvest, on the 14th March, each of the eight plots was divided into two. The second to the fifth row formed one strip and the seventh to the tenth row formed a second strip. Thus the strips were in order mosaic-free, mosaic, mosaic, mosaic-free, replicated four times. Each strip was 4 yards broad and forty yards long. The weight in maunds of stripped cane was as follows :—

F	M	Mosaic-free	Mosaic
1	2	9·10	9·03
4	3	9·12	7·88
5	6	9·03	8·11
8	7	8·06	6·93
9	10	7·96	7·27
12	11	7·92	7·61
13	14	7·88	7·09
16	15	9·24	8·45
Mean		8·53	7·79
Difference		·74 or 8·6 per cent.	

The statistical figures to determine the significance of the differences between the series of pairs of plots are summarised below.

Co. 213	Mean difference	Standard deviation of the differences	Student's Method	
			Mean diff. St. Dev.	Odds
Cane	2·25	3·61	·62	20
Juice in sample	1·6	1·79	·9	81
Brix	·81	·52	1·5	1428
Sucrose	·99	·77	1·8	555
Glucose	·058	·116	·5	11
Purity	1·56	2·26	·69	28
Co. 205				
Cane	·74	·37	2·	very great
Glucose	·04	·08	·5	8

The other differences in Co. 205 are too small to be significant.

In these experiments, then, with regard to the weight of cane of Co. 213, the odds are 20 to 1 against the occurrence of a difference as great as 2·25 mds. or 4·6 per cent. between the two sets of observations of Co. 213 being due to chance alone or the odds are 20 to 1 against such a difference as 4·6 per cent. being found if both the series of Co. 213 plots had been planted either with mosaic-free cane alone or with mosaic cane alone. Similarly the odds against the difference of yield, *viz.*, 74 mds. or 8·6 per cent. in mosaic-free and mosaic cane of Co. 205 being a fortuitous difference is very great. Also from a consideration of the odds of the various other items compared we may conclude that the differences are real though there is some doubt about the glucose in both varieties where the odds are rather low. On the whole, then, in these two experiments the mosaic disease has lowered the weight yield of cane by a small percentage and has lowered slightly the quality of the juice in Co. 213. These experiments show that, in Pusa, in the conditions existing in the season 1930-31, the loss of tonnage was small in Co. 205 and Co. 213, and that the deterioration of juice was small in Co. 213 but did not show in Co. 205. Still such a reduction in purity, slight though it appears, is an important factor for the manufacturer and taken on a fifteen lakh crop, would represent a loss to the mill of approximately Rs. 20,000 for the season.

From general eye observation and comparative records of yields the other Coimbatore seedling canes that reach field-scale in Pusa behave in much the same way. Though quite susceptible to mosaic they are highly tolerant. Co. 214 is the only one of them that does not take this disease. It may be that because of the short growing season in North Bihar mosaic does not have the same effect on the yield of the cane as it has on tropical long-period cane, and we certainly never see the markings on the stem recorded elsewhere. The results of this year's experiment may reasonably be taken as applicable to Coimbatore seedling canes in North Bihar and the adjacent parts of the United Provinces but they may or may not be applicable to the rest of northern India. The conditions in south and western India are so different that these results can hardly have any value there and it is possible and perhaps likely that greater losses may be induced both in tonnage and quality of juice. The experiment will be repeated for at least two seasons more with Co. 213 only, as the other cane has become unpopular with the mills, chiefly because of its high fibre content and lower yield. A similar experiment with the thick cane under irrigation in tropical India would yield valuable data, though here probably the lay-out of the experiment would have to be modified because the disease spreads far more rapidly as shown by results in Coimbatore in 1928 and subsequent years

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A BACTERIAL WHITE SOFT ROT OF TURNIP.

BY

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(Received for publication on the 18th June 1931.)

A white soft rot of turnip was noticed at Pusa, in the Kitchen garden area, in February, 1931. A large number of well-grown turnips were affected and were found to give off a putrid smell after softening. In most of the affected roots the softening had gone too far and considerable portions of them had been reduced to a white pulp before the disease could be detected. From the turnip plot a nasty smell was emanating and careful examination revealed that some of the turnip roots showed areas which appeared partially water-soaked and were soft to the touch. While pulling out the affected roots, it was noticed that the rotten portions were left in the ground. A considerable number of the roots were damaged in this way.

Symptoms of the disease.

In case of early infection there is nothing abnormal in the appearance of the foliage but in advanced cases leaves turn yellow and droop down. On the roots there are areas, not confined to any particular part, having the appearance of soft water-soaked patches of a colour paler than the sound and firmer portion. Inside these soft patches the tissues are all reduced to white pulp from which a putrid smell emanates.

Method of attack of the disease.

The method of infection is probably through injury caused either during inter-cultivation or by insects. Healthy, growing, plants when inoculated with pure culture or with a little diseased tissue by means of sterile needle or knife showed symptoms of the disease after about two days.

Laboratory examination of the naturally infected roots showed that decaying tissues were swarming with motile bacteria. Platings were made from a partly rotted turnip and chiefly one type of organism was found on the plates and isolated in pure culture, which when inoculated into raw sterile turnips produced the characteristic rotting. The organism was re-isolated from them and produced

rotting by wound inoculation on sterile roots and on sterile pieces of turnip, potato, sweet potato, artichoke, beet-root, brinjal, radish, onion, carrot, *Cucumis sativus* (*khira*), and musk melon. Corms of a garden flower plant of Amaryllidaceæ order was also easily attacked. Stalks and heads of cauliflowers and stalks of cabbage (but not leaves) rotted readily.

The causative organism.

The growth, in pure culture, of the organism resembled generally that of the group of bacteria which are known, in other countries, to cause soft rots of vegetables. Study of its morphological and cultural characters shows the organism to closely resemble *Bacillus aroideæ* [Townsend, 1904] or *Bacillus melonis* [Giddings, 1910] with minor differences. In spite of repeated trials, the organism did not ferment milk with gas, whereas gas was found to be formed in milk cultures of *B. aroideæ* and *B. melonis* by the previous investigators. Our organism seems to be a variant of *B. aroideæ* or *B. melonis*.

Brief description of the causative organism.

A short rod measuring about 1·0 to 1·5 μ × 0·5 to 0·7 μ, generally single or in twos, motile by means of 6-8 peritrichiate flagella; no spores; no capsule; gram negative; facultative anaerobic; agar colonies round, small, glistening, slightly raised, moist, greyish-white, smoky by direct transmitted light, opalescent in oblique light; gelatine liquefied, milk curdled and slightly peptonized without formation of gas; nitrates reduced, slight indol production; growth in Uschinsky's solution without pellicle formation; no growth in Cohn's solution; good growth in Fermi's solution; acid without gas from dextrose, maltose, lactose, galactose, sucrose, glycerol, mannitol; slight diastatic action; thermal death point 50°C. Reversal of reaction after some days' growth in carbohydrate media was noticed. In broth containing 0·1 per cent. glucose, sucrose, and lactose there was reversal from pH 4·8 to 6·2, from pH 5·0 to 5·2 and from pH 5·4 to 6·0 respectively. In broth containing higher percentages of these sugars, *viz.*, 0·3 per cent. and 1·0 per cent. marked reversion was not noticed.

Harding and Morse [1909] and others have observed that *B. carotovorous* and some others of the soft-rot organisms produce pectinase, an enzyme which has the power of softening middle lamella of some of the vegetables. Ten days' growth of the organism in beef broth was filtered through a Berkefeld filter and the sterile filtrate tried on sterile turnip and potato slices produced characteristic softening.

A search of the literature on wet rots of vegetables and fruits shows that the above description of the symptoms of the disease and of the causative organism agree only in certain respects with the descriptions given by previous workers.

A comparative study of the published papers further shows that there are possibly three kinds of closely resembling organisms which cause turnip rots. The symptoms of the disease found by the different investigators also vary with the morphological and cultural characters of the causative organism which are described hereafter.

(*a*) The disease caused by an injury at the crown of the foliage and confined to the core or the internal tissues without affecting the outer skin is attributed to an organism with single polar flagellum, *Pseudomonas destructans* by Potter [1901], by Jones [1922] whose organism is similar to *Ps. destructans* (Potter), and by Johnson and Adams [1910].

(*b*) Disease starting from the crown until the whole root from the top to the base is involved is described by Wormald and Harris [1925]. The centre becomes a mass of rotten pulp and the rotten parenchymatous tissues disappear leaving the vascular cylinder only as a fibrous net work. The causative organism which has peritrichic flagella is, however, described as similar to *B. carotovorus* (Jones) with the group number 221·1113022 as determined by Harding and Morse (which agrees with the descriptions of Wormald and Harris).

Priestley and Lechmere [1910] describe a similar disease of Swedes caused by an organism similar to *B. oleraceæ* (Harrison) whose group number is identical with the group No. of *B carotovorus* as determined by Harding and Morse [1909].

(*c*) The disease described in this paper differs from the above two kinds in that the crown and leaves are not affected till nearly the whole root is rotted, as it starts from the sides of the root where the original injury might have been caused. This disease is ascribed to an organism similar to *B. aroideæ*[1] [Townsend, 1909] or *B. melonis*[2] [Giddings, 1910] with peritrichic flagella. The group number of this organism 221·2223022 as determined by us is the same as that of an organism, Turnip Rot D. Vermont, as determined by Harding and Morse and agrees with that of *B. aroideæ* or *B. melonis*. Massey [1924] describes a similar organism with peritrichic flagella causing tomato rot, and considers it to be identical with *B. aroideæ*. The description of the Pusa turnip rot organism agrees with *B. aroideæ* Townsend, and differs from *B. melonis* (Giddings) and Massey's Tomato rot organisms in not producing gas from milk as we failed to observe any gas production in milk, whey or neutralized whey.

Remedial measures.

Direct remedial measures against diseases of root crops growing partly, if not wholly, underground are not feasible. The only preventive measure that can be suggested is rotation with other crops, the fruits of which do not come in contact with the soil.

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THE INHERITANCE OF CHARACTERS IN RAGI, *ELEUSINE CORACANA* (GAERTN.),

PART II.

GRAIN COLOUR FACTORS AND THEIR RELATION TO PLANT PURPLE PIGMENTATION*

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(With Plates LVIII-LX.)

Brown is the predominant grain colour of *ragi*. There are however a few minor races whose grain colour is white. The brown pigment is confined to the testa or the outer layer of the seed-coat (Plate LVIII.)

As already described in Part I, †*ragi* plants are either green-throughout or purple pigmented in parts. It was noticed that all the white-grained races consisted of plants that were green-throughout. The marked absence of white grains in purple-pigmented plants stimulated the pursuit of the inheritance of this brown colour in the grain and its relationship to the purple pigment in the plant.

In January 1928, in the mother population of white-grained green-throughouts, a few brown-grained, purple-pigmented plants were noticed, with that characteristic aspect that gave a reasonable suspicion of their being natural hybrids.

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* Paper read at the 18th Session of the Indian Science Congress at Nagpur (Jan. 1931) with fuller data and an added chapter on Depth of Brown.

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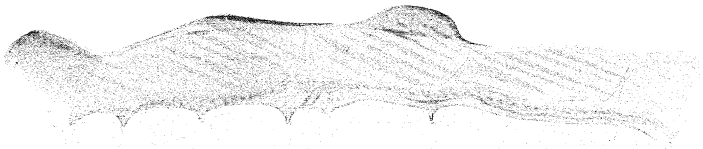
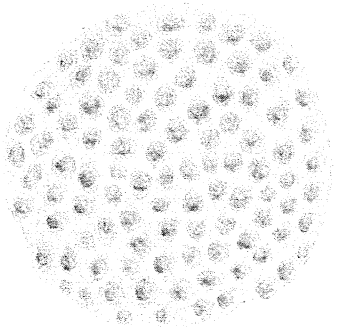
SECTION OF *RAGI* SEED COAT.





Brown Grain

White Grain

PLATE LVIII.

Later in the year, five of these were sown and the second generation raised from them behaved as follows :—

TABLE I.

Ratio			Family No.	F_2 Behaviour		
Purple plant Brown grain	Green plant Brown grain	Green plant White grain		Purple plant	Green plant	
				Brown grain	Brown grain	White grain
			E. C.			
15	..	1	1200	763	..	50
15	..	1	1201	646	..	37
45	15	4	1202	426	151	25
45	15	4	1203	242	69	30
45	15	4	1204	630	211	53

It was obvious that a set of duplicate factors were at work, producing the brown of the grain and that the purple pigment of the plant was related to these. A large number of selections from three of these families, *viz.*, E. C. 1200, 1203, and 1204 were carried forward to elucidate these points. These families have been worked to further generations, E. C. 1200 to the F_3 and E. C. 1203 and E. C. 1204 to the fourth generation. Their behaviour is presented in Tables II to XII.

The following points are given to serve as a genetic introduction to these tables.

(1) Two factors designated B_1 and B_2 are at work either singly or together to produce the brown pigment of the *ragi* grain. In the absence of both the B factors the grain is white.

(2) A supplementary factor S working in association with either or both of the B factors is responsible for the production of plant purple pigmentation.

Abbreviations used.—The following abbreviations figure in the tables.

P. = Plant purple.
GT. = Plant Green-throughout.
Br. = Brown grain.
W. = White grain.

TABLE II.

Clan E. C. 1200 F_3.

(16 families.)

Ratio		Selection	F_2	F_3 Behaviour	
Purple plant Brown grain	Green plant White grain	No.	Character	Purple plant Brown grain	Green plant White grain
		E. C.			
15	1	1610	Purple plant . .	149	10
		1615	Brown grain . .	192	10
		1620	,, . .	174	15
3	1	1607	,, . .	199	45
		1611	,, . .	122	49
		1613	,, . .	163	38
		1614	,, . .	136	28
		1616	,, . .	114	55
		1617	,, . .	131	39
		1621	,, . .	161	64
All		1608	,, . .	All	
		1609	,, .	All	
		1612	,, . .	All	
		1618	,, . .	All	
		1619	,, . .	All	
	All	1622	Green plant . .		
			White grain . .		pure

This clan is obviously pure for the S factor and segregating for both the factors B_1 and B_2. The factorial composition of E. C. 1200 is therefore $B_1\ b_1\ B_2\ b_2$ SS.

Clan E. C. 1203 has proved excellent material for illustrating the segregation for all the three factors B_1, B_2, and S. Table III represents its third generation and considering the small number of selections representing this generation, *viz.*, 21, the occurrence of all the ten kinds of experiences to be theoretically expected in this generation (Plate LIX) is a remarkable and happy coincidence.

RAGI - GRAIN & PLANT PIGMENT RELATIONSHIPS.

♂ ♀

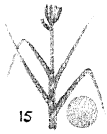
Parents

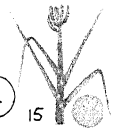
F_1

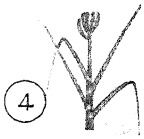
F_2

F_3 (64)

(8)



(4) 

(4) 

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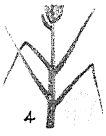
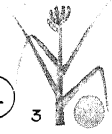
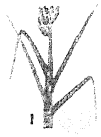
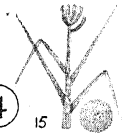


(4) 



(4) 

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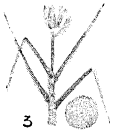
(14) 

(7)

TABLE III.

Clan E. C. 1203-F_3.

(21 Families.)

Ratio			Selection No.	F_2 Character	F_2 Behaviour		
Purple plant	Green plant	Green plant			Purple plant	Green plant.	
Brown grain	Brown grain	White grain			Brown grain	Brown grain	White grain
			E. C.				
45	15	4	1426	Purple plant Brown grain .	132	43	6
9	3	4	1430	Do. .	133	36	58
15	..	1	1428	Do. .	223	..	11
3	..	1	1423	Do. .	218	..	51
3	..	1	1425	Do. .	154	..	39
3	..	1	1431	Do. .	216	..	57
3	..	1	1432	Do. .	192	..	63
3	1	..	1422	Do. .	116	43	..
3	1	..	1424	Do. .	153	48	..
3	1	..	1427	Do. .	205	57	..
3	1	..	1429	Do. .	195	67	..
All	..	..	1421	Do. .	All	..	..
..	15	1	1434	Green plant Brown grain . .	..	182	10
..	3	1	1433	Do. .	..	184	42
..	All	..	1435	Do. .	..	All	..
..	All	..	1436	Do. .	..	All	..
..	All	..	1437	Do. .	..	All	..
..	All	..	1438	Do.	..	All	..
..	..	All	1439	Green plant White grain . .	..	..	All
..	..	All	1440	Do. .	..	..	All
..	..	All	1441	Do. .	..	..	All

A fairly comprehensive F_4, with representatives from each of the 7 kinds of segregates in the F_3, is presented in Tables IV to X, and their study will leave no doubt as to the interpretation of the inter-play of these three factors detailed above.

TABLE IV.

Clan E. C. 1203-F_4.

F_4 from Family No. E. C. 1426 (B_1 b_1 B_2 b_2 Ss) of Table III.

(20 Families.)

Genetic interpretation	Selection No.	Character of selection in F_3	F_4 Behaviour		
			P. Br.	GT. Br.	GT. W.
Segregating for B_1 B_2 and S.	E. C. 1880	P. Br.	80	18	7
	1882	,,	70	23	10
	1892	,,	43	17	5
Segregating for S. and one B— Absence of the other B	1888	,,	63	12	28
Segregating for B_1 and B_2— Pure for S.	1876	,,	111	..	4
	1883	,,	95	..	9
Segregating for one B— Pure for S— Absence of the other B.	1878	,,	65	..	22
	1879	,,	62	..	15
	1884	,,	98	..	29
	1886	,,	69	..	13
	1887	,,	69	..	27
	1894	,,	47	..	14
Segregating for S— Pure for B. (one or both)	1885	,,	92	29	..
	1889	,,	64	30	..
	1890	,,	80	32	..
	1891	,,	79	20	..
	1893	,,	71	20	..
	1895	,,	51	21	..
Pure for S. and B. (one or both)	1877	,,	All	..	..
	1881	,,	All	..	..

TABLE V.

Clan E. C. 1203-F_4.

F_4 from Family No. E. C. 1430 (B_1 b_1 b_2 b_2 Ss) or (b_1 b_1 B_2 b_2 Ss) of Table III.

(16 Families.)

NOTE.—One B factor is absent in the whole of this F_4.

Genetic interpretation	Selection No.	Character of selection in F_3	F_4 Behaviour		
			P. Br.	GT. Br.	GT. W.
	E. C.				
Segregating for B. and S.	1918	P. Br.	48	10	18
	1920	,,	58	12	20
	1922	,,	69	23	26
	1923	,,	55	21	18
Segregating for B—					
Pure for S.	1919	,,	58	..	24
	1921	,,	70	..	30
	1924	,,	77	..	25
Segregating for S—					
Pure for B.	1917	,,	68	26	..
Pure for S. and B.	1925	,,	pure	..	..
Segregating for B—					
Absence of S.	1537	GT. Br.	..	28	11
	1926	,,	..	48	15
Pure for B—					
Absence of S.	1927	,,	..	pure	..
Absence of both S. and B.	1538	GT. W.	..	..	pure
	1539	,,	..	..	pure
	1540	,,	..	..	pure
	1541		..	..	pure

Table VI.

Clan E.C. 1203-F_4.

F_4 from Family No. E. C. 1428 (B_1b_1 B_2b_2 SS) of Table III.

(16 Families.)

Note :—This F_4 is pure for S.

Genetic interpretation	Selection No.	Character of selection in F_3	F_4 Behaviour	
			P. Br.	GT. W.
	E. C.			
Segregating for B_1 and B_2	1897	P. Br.	122	9
	1900	,,	101	10
	1904	,,	94	5
Segregating for one B. Absence of the other B.	1899	,,	67	16
	1903	,,	29	12
	1910	,,	86	34
Pure for B (one or both)	1896	,,	All	..
	1898	,,	All	..
	1901	,,	All	..
	1902	,,	All	..
	1905	,,	All	..
	1906	,,	All	..
	1907	,,	All	..
	1908	,,	All	..
	1909	,,	All	..
Absence of B_1 and B_2	1911	GT. W.	..	pure

TABLE VII.

Clan E. C. 1203-F_4.

F_4 from Family No. E. C. 1425 ($B_1b_1b_2b_2$ SS) or (b_1b_1 B_2b_2 SS) of Table III.

(5 Families.)

NOTE :—This F_4 is pure for S and for the absence of one B.

Genetic interpretation	Selection No.	Character of selection in F_3	F_4 Behaviour	
			P. Br.	GT. W.
	E. C.			
Segregating for B.	1871	P. Br.	71	23
	1872	,,	pure	..
Pure for B.	1873	,,	pure	..
	1874	,,	pure	..
Absence of B.	1875	GT. W.	..	pure

TABLE VIII.

Clan E. C. 1203-F_4.

F_4 from Family No. E. C. 1429 (B_1B_1 B_2B_2 Ss) or (B_1b_1 B_2B_2 Ss), or (B_1B_1 B_2b_2 Ss) of Table III.

(5 Families.)

NOTE :—This F_4 is pure for B (one or both).

Genetic interpretation	Selection No.	Character of selection in F_3	F_4 Behaviour	
			P. Br.	GT. Br.
	E. C.			
Segregating for S.	1915	P. Br.	67	27
	1912	,,	All	..
Pure for S.	1913	,,	All	..
	1914	,,	All	..
Absence of S.	1916	GT. Br.	..	pure

TABLE IX.

Clan E. C. 1203-F_4.

F_4 from Family No. E. C. 1434 (B_1 b_1 B_2 b_2 ss) of Table III.

(16 Families)

Note :—S is absent from the whole of this F_4.

Genetic interpretation	Selection No.	Character of selection in F_3	F_4 Behaviour	
			GT. Br.	GT. W.
	E. C.			
Segregating for B_1 and B_2	1936	GT. Br.	85	13
	1937	,,	100	7
	1938	,,	101	7
Segregating for one B—Absence of the other B.	1933	,,	101	30
	1934	,,	98	28
	1939	,,	56	20
	1940	,,	61	21
	1945	,,	70	23
	1946	,,	92	22
	1947	,,	59	22
Pure for B (one or both)	1935	,,	All	..
	1941	,,	All	..
	1942	,,	All	..
	1943	,,	All	..
	1944	,,	All	..
Absence of B_1 and B_2	1948	GT. W.	..	pure

TABLE X.

Clan E. C. 1203-F_4.

F_4 from Family No. E. C. 1433 (B_1 b_1 b_2 b_2 ss) or (b_1 b_1 B_2 b_2 ss) of Table III.

(5 Families.)

Note :—S and one B factor are absent from the whole of this F_4.

Genetic interpretation	Selection No.	Character of selection in F_3	F_4 Behaviour	
			GT. Br.	GT. W.
	E. C.			
Segregating for B.	1929	GT. Br.	81	27
	1931	,,	101	20
Pure for B.	1928	,,	pure	..
	1930	,,	pure	..
Absence of B.	1932	GT. W.	..	pure

E. C. 1204, the sister clan to E. C. 1203, has been dealt with equally elaborately and its behaviour in the F_3 is presented in Table XI.

TABLE XI.

Clan E. C. 1204-F_3.

(20 Families.)

Ratio			Selection No.	F_2 Character	F_3 Behaviour		
Purple plant	Green plant	Green plant			Purple plant	Green plant	
Brown grain	Brown grain	White grain			Brown grain	Brown grain	White grain
			E. C.				
45	15	4	1442	Purple plant .	159	47	11
45	15	4	1448	Brown grain .	215	78	22
45	15	4	1449	,, .	228	104	16
9	3	4	1444	,, .	140	32	36
9	3	4	1451	,, .	151	66	41
9	3	4	1452	,, .	167	66	67
3	1	..	1443	,, .	165	63	..
3	1	..	1446	,, .	176	59	..
3	1	..	1447	,, .	233	81	..
3	1	..	1453	,, .	209	85	..
All	..	..	1445	,, .	All	..	..
All	..	..	1450	,, .	All	..	..
..	15	1	1455	Green plant .	..	222	13
..	15	1	1459	Brown grain .	..	209	15
..	3	1	1454	,, .	..	226	53
..	3	1	1456	,, .	..	186	54
..	All	..	1457	,, .	..	All	..
..	All	..	1458	,, .	..	All	..
..	..	All	1460	Green plant .	..	..	pure
..	..	All	1461	White grain .	..	..	pure

A summary of its F_4 appears in Table XII.

TABLE XII.

Clan E. C. 1204-F_4.

F_4 from Families E. C. 1444, 1447, 1448, 1454 and 1459 of Table XI.

(70 Families.)

Genetic interpretation	Selection No.	Character of selection in F_3	F_4 Behaviour		
			P. Br.	GT. Br.	GT. W.
	E. C.				
Segregating for B_1, B_2 and S. . .	1715, 1716, 1719, 1726.	P. Br.	400	104	36
Segregating for S and one B— Absence of the other B . . .	1542, 1545, 1549, 1550, 1552, 1553, 1717, 1723.	,,	941	316	383
Segregating for S— Pure for B (one or both) . . .	1551, 1707, 1708, 1709, 1714, 1718, 1721, 1724, 1725, 1727.	,,	1077	329	..
Segregating for B_1 and B_2— Pure for S.	1713, 1720, 1722 .	,,	568	..	37
Segregating for one B— Pure for S.	1546 . . .	,,	175	..	55
Pure for S and B (one or both) . .	1543, 1544, 1548, 1710, 1712.	,,	All	..	..
Segregating for B_1 and B_2— Absence of S.	1728, 1738, 1740, 1743, 1744, 1750, 1753, 1755, 1756.	GT. Br.		1179	65
Segregating for B— Absence of S and the other B. . .	1543, 1544, 1548, 1732, 1733, 1739, 1741, 1742, 1751, 1754, 1755, 1756.	,,		1058	344
Pure for B (one or both)— Absence of S.	1557, 1711, 1729, 1730, 1731, 1734, 1735, 1737, 1745 to 1749, 1752, 1754.	,,		All	..
Absence of B_1 and B_2 . . .	1736, 1757, 1758 .	GT. W.			pure

To confirm the introductory hypothesis, artificial crosses were made between two green-throughout plants, one white-grained and the other brown-grained, of the following genetic composition :—

Cross No. E. C. CXLIII (1929)

♀ E. C. 1540 (of Table V) — Green-throughout, White grain — bbSS

♂ E. C. 1537 (of Table V) — Green-throughout, Brown grain — BBss

Four first generation plants raised from this cross between green plants gave, true to expectation, purple-pigmented plants with brown grain, whose second generation has given the expected 9 : 3 : 4 ratio of purple plants with brown grain, and green plants with brown and with white grain—*vide* Table XIII.

TABLE XIII.

Cross CXLIII-F_2.

Family No.	F_2 Behaviour		
	Purple plant	Green-throughout plant	
	Brown grain	Brown grain	White grain
E. C 1812	122	41	53
E. C. 1813	130	40	62
E. C. 1814	133	41	43
E. C. 1815	131	38	45
Total .	516	160	203

$X^2 = 2{\cdot}35$ $P = {\cdot}3$

Ragi is associated with its characteristic brown grain. Unlike other cereals there is not any wealth of grain colour. It is all one dull drab. People using this grain get reconciled to the brown tint of the cooked gruel. The more agreeable white *ragi* is comparatively less vigorous and poor yielding and is consequently rare in cultivation. Nevertheless it required a white-grained *ragi* with the S factor, to figure in a cross and resolve both the plant purple and the grain brown of the *ragi* into their genetic compositions. This fact is of considerable significance in the evolution and survival value of the existing varieties of cultivated *ragi*.

Depth of Brown.

As already mentioned brown is the common colour of *ragi*. It is so characteristic of this cereal that this particular tint of brown has been designated ragi brown. Certain races are met with in which the ragi colour of the grain takes on a darker shade (Plate Lx). Given fair weather and normal ripening, the separation between the ordinary ragi brown and the dark ragi brown is definite. Over-ripeness or a downpour of rain tends to make the normal colour dark and the dark colour reddish black with the result that the separation of the two gets to be rather difficult.

These difficulties notwithstanding, the dark ragi brown has been found to be brought about by a definite factor—D—which acting on the ragi brown makes it dark brown.

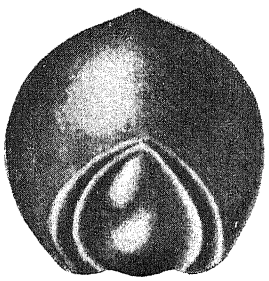
The following segregates prove this point. In judging the trend of these figures, their un-uniform ripening coupled with odd showers intervening between readings will have to be remembered. The pure browns and the homozygous dark browns of the F_3 and F_4 leave no doubt on the general question of a single factor segregation.

Table XIV.

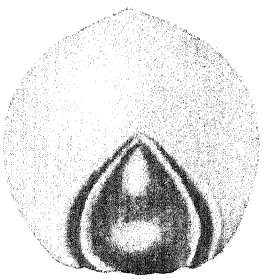
Segregation for depth of brown.

Generation	Number	Grain colour	
		Dark brown	Ragi brown
Natural Cross (1927)			
F_2	E. C. 1300	126	22
F_3			
Character of selection.			
Dark brown	E. C. 1559	27	10
,,	E. C. 1560	64	23
,,	E. C. 1563	49	24
,,	E. C. 1564	34	24
,,	E. C. 1561	pure	..
,,	E. C. 1562	pure	..
Ragi brown	E. C. 1565	..	pure
,,	E. C. 1566	..	pure

RAGI GRAIN.



DARK BROWN



RAGI BROWN

TABLE XIV—(*contd.*).

Segregation for depth of brown—(contd.).

Generation	Number	Grain colour	
		Dark brown	Ragi brown.
F_4 (*from Family E. C. 1560*)			
Dark brown	E. C. 2156	8	3
„	E. C. 2157	7	3
„	E. C. 2159	24	7
„	E. C. 2160	40	14
„	E. C. 2158	pure	..
„	E. C. 2161	pure	..
Ragi brown	E. C. 2162	..	pure
	Total of segregates	379	130

This factor—D—for depth is independent of the various plant purple pigmentation factors. The history of Clan E. C. 1523 in which the —D—factor figures along with segregations for plant purple pigmentation and grain colour, proves its independent existence and its individuality as a simple deepener of the action of B factors for grain colour (*vide* Table XV).

TABLE XV.

D independent of B S and I factors.

Generation	Number	Grain colour						
		Dark brown			Ragi brown			White
		(Plant.) P	*L. P.	G. T.	P.	L. P.	G. T.	G. T.
Natural Cross (*1929*)								
F_2	E. C. 1523	96	34	45	42	9	17	16
F_3								
Character of selection.. Grain. Plant.								
Dark brown . P.	E. C. 1952	53	39	19	35	21	15	53
„ . „	E. C. 1956	90	40	50	57	11	16	..
„ . „	E. C. 1949	107	76	..	41	17	..	..
„ . „	E. C. 1950	99	50	40	..	..	..	40
„ . „	E. C. 1951	108	34	31	..	..	..	..

TABLE XV—(*contd.*).

D—independent of B S and I factors—(contd.).

Generation		Number	Grain colour						
			Dark brown			Ragi brown			White
			(Plant) P.	*L. P.	G. T.	P.	L. P.	G. T.	G. T,
Grain. Dark brown .	Plant. P.	E. C. 1953 .	160	49	76	..	..	..	..
,, .	,,	E. C. 1954 .	141	72	58	..	..	..	..
,, .	,,	E. C. 1955 .	112	41	58	..	..	..	..
,, .	L. P.	E. C. 1963 .	..	52	27	..	22	6	10
,, .	,,	E. C. 1965 .	..	46	17	..	36	12	6
,, .	,,	E. C. 1966 .	..	60	33	..	17	13	8
,, .	,,	E. C. 1961 .	..	80	26	..	..	..	12
,, .	,,	E. C. 1964 .	..	109	37	..	..	..	..
,, .	,,	E. C. 1962 .	..	All	..	..	..	..	..
,, .	G. T.	E. C. 1970 .	..	..	100	..	..	..	29
,, .	,,	E. C. 1969 .	..	..	82	..	..	32	..
,, .	,,	E. C. 1971 .	..	..	93	..	..	41	..
,, .	,,	E. C. 1972 .	..	..	94	..	..	33	..
Ragi brown .	P.	E. C. 1957 .	..	..	..	190	..	63	10
,, .	,,	E. C. 1959 .	..	..	..	75	..	37	31
,, .	,,	E. C. 1958 .	..	..	..	97	..	29	..
,, .	,,	E. C. 1974 .	..	..	..	84	..	30	..
,, .	,	E. C. 1960 .	..	..	..	110	46	..	..
,, .	L. P.	E. C. 1967 .	..	..	..	..	84	30	..
,, .	,,	E. C. 1968 .	..	..	..	..	80	26	..
,, .	G. T.	E. C. 1973 .	..	..	..	..	..	All	..
White . .	,,	E. C. 1975 .	..	..	..	..	..	..	All
,, . .	,,	E. C. 1976 .	..	..	..	..	..	..	All

*L. P. = Localised Purple.

It is noteworthy that the 28 families of the third generation presented in Table XV, bring out the inter-play of the five factors B_1, B_2, S, I, and D. Selections for the extraction of a green-throughout with white grain and the D factor, are being worked on for material to cross with.

Summary.

The characteristic brown colour of the ragi grain has been designated ragi brown. Two factors B_1 and B_2 either alone or together are capable of producing this brown. A third factor S in association with either or both of the B factors, produces plant purple pigmentation. This factor accounts for the absence of white-grained *ragi* in purple-pigmented plants. The S factor is carried by some races of white grains.

A factor D that deepens the effect of the B factors behaves as a simple dominant. This is independant of the factors concerned in the plant purple pigmentation and is not in selective association with either of the B factors.

THE INHERITANCE OF CHARACTERS IN RAGI, *ELEUSINE CORACANA* (GAERTN.),

PART III.

STERILITY.

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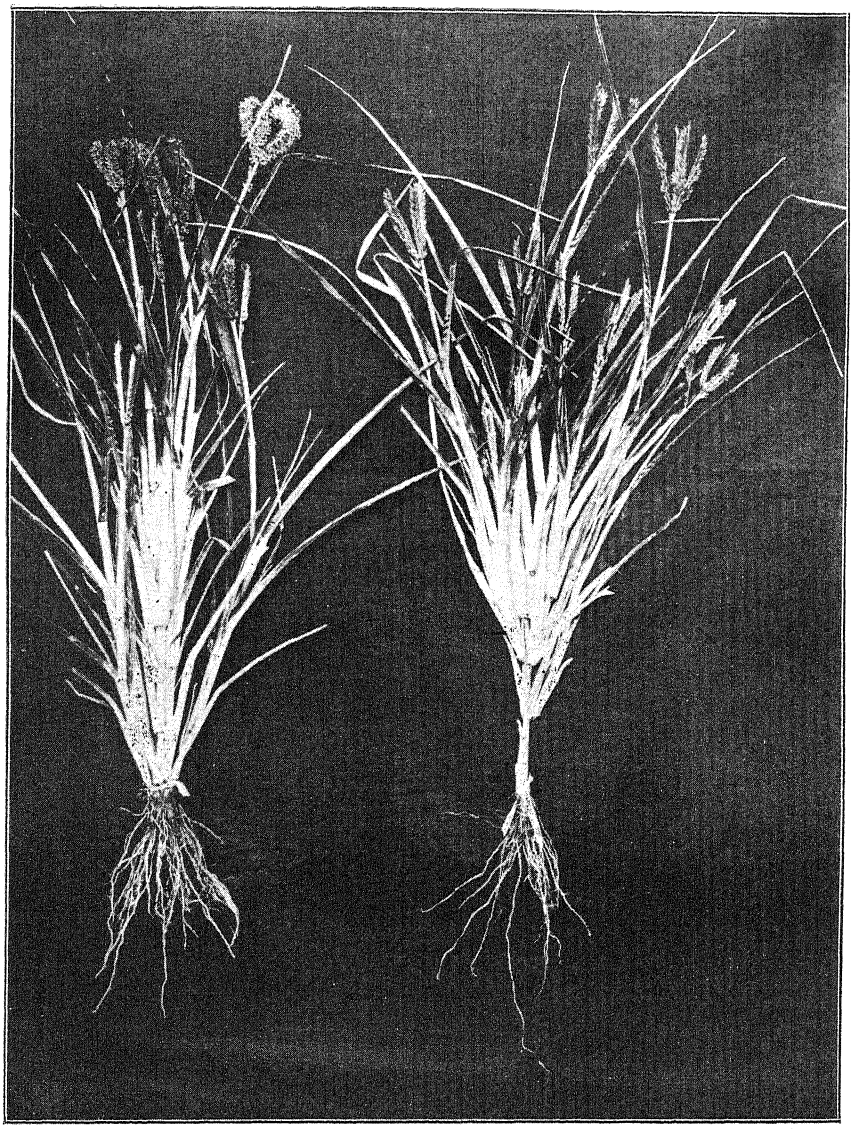
(With Plates LXI-LXIII.)

Sterility is occasionally met with in the *ragi* plant. It manifests itself in an almost complete failure to set seed in the ear-heads, giving them a blighted look. Such plants start to grow vigorously, branch quick and profuse, flower late and put forth numerous heads giving the plant a low bushy aspect. The anthers lack the free and quick protrusion which gives the healthy ear-heads that fullness characteristic of the blooming period.

The stigmas are healthy and receptive though for lack of pollen remain characteristically naked. Most of the anthers do not dehisce, though there are enough stray ones opening out to keep the race going. The net result of this defect is the production of a mass of sapped up ear-heads dotted with odd grains that have managed to develop. A typical sterile plant together with a healthy one is shown in Plate LXI.

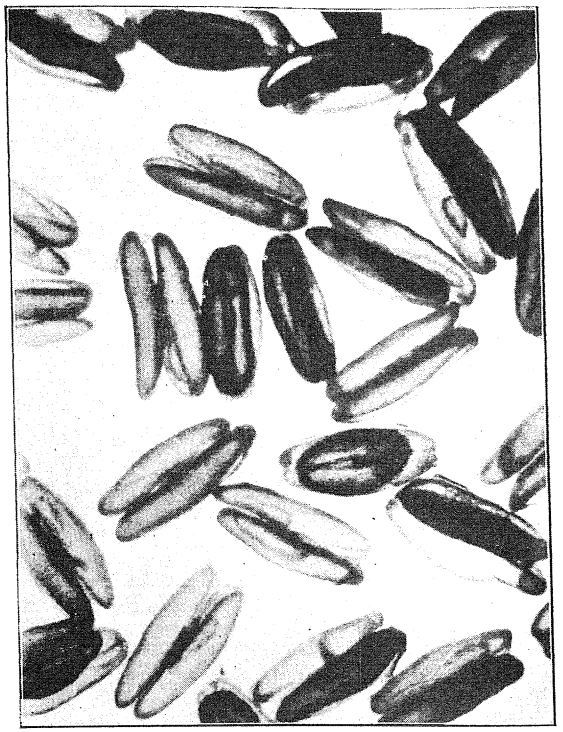
Many forms of sterility have been met with, two of which have lent themselves to definite pursuit. They are due to (i) a non-dehiscence of anthers, and (ii) an agglutination of the pollen grains. These are dealt with separately below.

PLATE LXI.

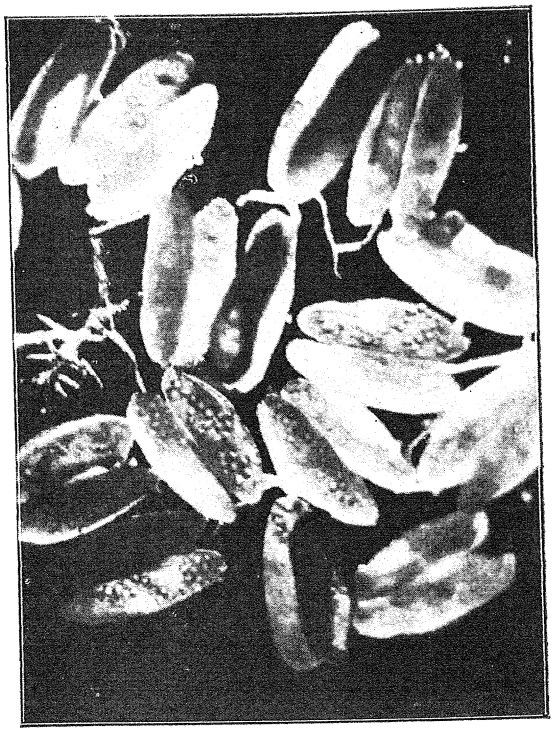


FERTILE AND STERILE PLANTS.

STERILITY.



DEHISCED ANTHERS.



NON-DEHISCED ANTHERS.

STERILITY.

STERILITY—NON-DEHISCENCE OF ANTHERS.

Description :—The first type of sterility is the result of non-dehiscence of anthers. In sterile plants the anthers are of the same size and shape as in the healthy ones. They do not dehisce, but are full of pollen grains (Plate LXII) and are held rigidly up by the filaments for a considerably longer time than in the normals. Most of the anthers are like this, though a few do dehisce and help to set a few seeds. In plants with no purple pigmentation these undehisced anthers have an unhealthy whitish look in contrast to the light yellow of the normals. In purple-pigmented plants the non-dehiscing anthers have the purple dotting and daub on them considerably reduced and practically confined to a weak zone of purple along the suture groove. The pollen grains inside these anthers are free and healthy, full of contents, and respond normally to the iodine test and have been found to be viable.

Incidence :—From the very nature of the character it is impossible for it to exist in a pure state unless under selfed conditions. Individual ear-heads have been selfed at the Millets Breeding Station, and have proved true to sterility as will be evidenced by the following figures :—

Year of selfing	Family No.	Population of steriles	Natural crosses fertiles
1927	E. C. 945	66	0
1927	E. C. 946	144	0
1928	E. C. 941	52	0

The range of setting in sterile families has been worked out on selfed primary heads in family No. E. C. 1371 on a population of 40 individuals and has been found to vary from as few as 5 grains to 572 grains with an average of 169 grains. In a sister family of fertiles, *viz.*, E. C. 929, similar counts on 40 selfed heads gave a range from 590 to 2788 grains with an average of 1524 grains. This manifestation of sterility naturally varies with the type of ear-head concerned. In family E. C. 1167 with a heavily branched and compact ear-head, with numerous flowers, counts on 30 sterile plants gave a range from 209 to 1357 grains with an average of 815 grains. In a sister family of normals, *viz.*, E. C. 1165 of similar ear-heads, grain counts on a population of 10 gave a range of 1665 to 4608 with an average of 2831 grains. The broad fact is patent that in otherwise related pure lines, sterility manifests itself in a low, though well marked, degree of setting.

Under natural conditions of flowering the steriles are liable to a chronic degree of natural crossing in the midst of other healthy individuals, as will be seen from the following figures :—

Unselfed sterile Family No.	Steriles	Fertile natural crosses
E. C. 731	49	47
E. C. 732	55	33
E. C. 733	43	51
E. C. 1371.	36	15
E. C. 1372.	8	6

There is absolutely no doubt about the nature of these natural hybrids. In E. C. 1371 given above the steriles were green throughout, but 13 out of the 15 natural crosses were purple-pigmented. In E. C. 1372 all the six natural crosses were purple ; so that in addition to fertility which spots a cross, we have the definite aid of purple pigmentation as an accessory help.

Many such natural crosses have been taken and grown to confirm their nature and the following few families are given illustrative of the undoubted composition of such crosses :—

No. of natural cross	F_2 segregation	
	Fertile	Sterile
E. C. 942	176	46
E. C. 943	149	48
E. C. 947	169	37
E. C. 953	187	51
E. C. 1368.	242	41

The following table gives other confirmatory data, purple pigmentation being added to the segregates :—

Number of natural cross	F_2 segregation			
	Fertile		Sterile	
	Purple plant	Green plant	Purple plant	Green plant
E. C. 944	104	47	30	13
E. C. 948	145	55	21	13
E. C. 949	106	28	16	7
E. C. 951	140	54	24	15
E. C. 952	127	55	34	5

It will incidentally be noticed that this anther non-dehiscence is practically unaffected by the presence or absence of purple pigmentation in the plant.

Inheritance :—This anther-non-dehiscence and the very sparse fertility consequent thereon has proved to be heritable and the history of clan E. C. 459, in which this experience was first met with and subsequently pursued to four generations, is given in Table I.

A single factor is responsible for the production of normally dehiscing anthers. This factor has been designated X. Its absence results in non-dehiscence.

TABLE I.

Clan No. E. C. 459.

(Segregation for the fertility factor X.)

——	Generation	Number	Characters	
			Fertile	Sterile
	Natural Cross (1925) (Xx)	..	Fertile	..
	F_2	E. C. 459 . . .	98	24
	F_3			
Genetic Behaviour.		*Character of selection.*		
Segregating for X . .	..	E. C. 728 Fertile . .	250	52
„ . .	..	E. C. 730 „ . .	234	64

TABLE I—*contd.*

Clan No. E. C. 459—contd.

——	Generation	Number	Characters	
			Fertile	Sterile
Pure for X . . .	..	E. C. 735 Fertile . .	Pure	..
,, . . .	..	E. C. 726 ,, . .	Pure	..
,, . . .	..	E. C. 727 ,, . .	Pure	..
,, . . .	..	E. C. 729 ,, . .	Pure	..
Absence of X . .	..	E. C. 731 Sterile . .	..	Pure
,, . .	..	E. C. 732 ,, . .	..	Pure
,, . .	..	E. C. 733 ,, . .	..	Pure
	F_4 (from E. C. 725	*and 726 families—XX.)*		
Pure for X . . .	..	E. C. 929 to E. C. 934 Fertile .	Pure	..
	F_4 (from E. C.	*730 family—Xx.)*		
Segregating for X . .	..	E. C. 935 to E. C. 939 Fertile .	357	90
Pure for X . . .	..	E. C. 936, E. C. 937, E. C. 938, E. C. 940 Fertile .	Pure	..
Absence of X . .	..	E. C. 941 Sterile . .	..	Pure
	F_4 (from E. C. 731	*and 732 families—xx.)*		
Absence of X . .	..	E. C. 945, E. C. 946 to E. C. 950 Sterile .	..	Pure

Selfed pure lines of purple-pigmented normals and steriles, and of green normals and steriles from clan E. C. 459 have been extracted.

In the field the differentiation between the fertiles and steriles is definite and unmistakable. Apart from the actual setting, the general look of the plant, the peculiar aspect of the heads and the general cumulative effect of this sterility, so mark out the steriles, that their classification has absolutely no element of doubt about it.

However, to have a definite measure to the segregation between fertiles and steriles, all the healthy main heads of a segregating family, E. C. 1368, were gathered and the number of set grains counted in each of them. These have been tabulated and given below in Table II, and show clearly even from this measurable point of view, the definiteness in the segregation for so vague a character as sterility.

TABLE II.

No. of grains on primary heads of family E. C. 1368 segregating for sterility.

Fertiles						Steriles
2971	1992	1716	1502	1299	988	497
2687	1974	1712	1501	1290	915	470
2581	1960	1707	1498	1286	908	465
2521	1937	1698	1491	1282	906	413
2502	1935	1696	1485	1281	888	397
2463	1934	1679	1483	1266	877	371
2440	1933	1674	1483	1265	875	370
2434	1932	1670	1481	1253	870	355
2393	1931	1668	1474	1243	848	353
2379	1924	1658	1473	1232	794	332
2357	1921	1644	1453	1231	..	297
2322	1909	1635	1446	1217	..	274
2319	1890	1610	1437	1217	..	269
2300	1887	1603	1429	1215	..	267
2278	1878	1593	1428	1214	..	256
2249	1877	1586	1427	1211	..	241
2217	1874	1584	1425	1205	..	238
2214	1871	1575	1424	1203	..	235
2209	1861	1569	1406	1191	..	227
2200	1857	1569	1400	1188	..	227
2198	1853	1565	1398	1176	..	214
2197	1844	1561	1393	1158	..	168
2188	1823	1560	1389	1158	..	153
2177	1811	1557	1385	1157	..	151
2147	1807	1551	1382	1154	..	145
2144	1805	1543	1378	1152	..	132
2138	1802	1537	1372	1144	..	130
2137	1796	1535	1365	1131	..	113
2111	1795	1529	1350	1113	..	109
2105	1791	1524	1344	1111	..	93
2083	1770	1524	1339	1109	..	90
2081	1758	1520	1337	1102	..	87
2072	1758	1517	1336	1092	..	85
2052	1749	1517	1332	1088	..	83
2046	1744	1516	1329	1086	..	77
2042	1744	1513	1329	1047	..	72
2029	1735	1510	1325	1039	..	40
2008	1729	1508	1315	1034	..	32
2007	1728	1503	1307	1026	..	8
1992	1722	1502	1304	991	..	7

STERILITY—AGGLUTINATED POLLEN GRAINS.

Description:—A second type of sterility has for its cause the absence of free and healthy pollen. A disintegrated mass of agglutinated pollen, devoid of con-

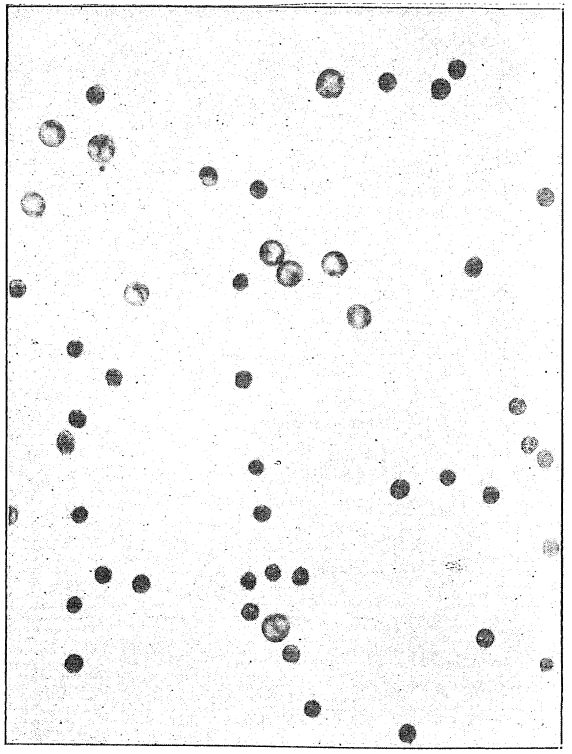
tents, gives the anther sacs a shrunken look and a reduced size. There is the usual poor emergence. The anthers dehisce. In colour, instead of the characteristic whitish look of the previous group, these have a creamy appearance and, in purple-pigmented varieties, lack that pigment on them. The pollen grains are inseparable and when forcibly teased out resolve into mis-shapen units (Plate LXIII) devoid of contents, and not reacting to iodine. A few flowers do produce viable pollen and perpetuate this type of sterility. In general effect plants that suffer from this type of sterility have the same empty look as the previous group.

Incidence:—The range of partial setting in this kind of sterility is about the same as in the non-dehiscence group. In family E. C. 1172 segregating for this type of sterility, the weight of grains from 10 sterile plants gave a range from 0·17 to 1·53 grams. Similar weights from 10 normal plants gave a range of 17·6 to 50·44 grams. Grain counts in the main heads of 20 plants in a pure line of steriles, *viz.*, E. C. 778, gave a range of 41 to 232 grains with an average of 132. Similar counts in the main heads of a fertile family, *viz.*, E. C. 774, gave a range of 1597 to 2752 grains with an average of 2164.

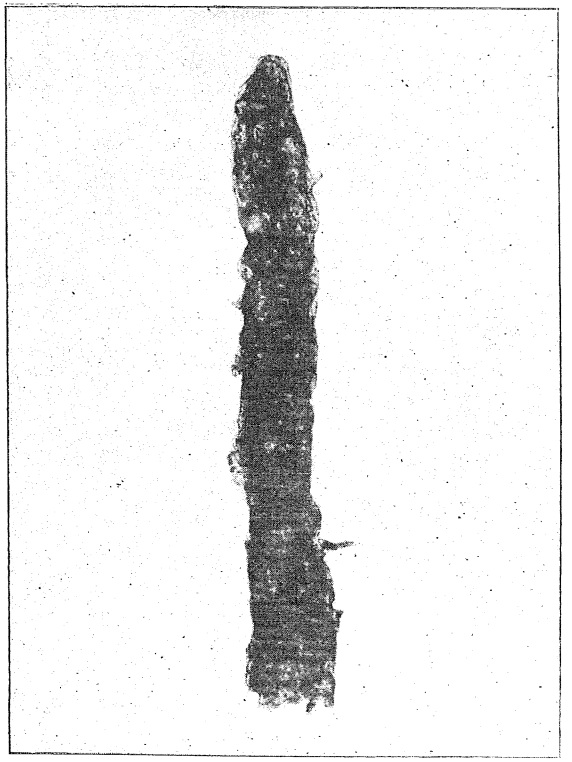
The extreme liability of this type of sterility to natural crossing will be realised from the following figures:—

Character of parent plant	Family No.	No. of Steriles	No. of Natural Crosses
Sterile	E. C. 777	6	46
„	E. C. 778	18	101
„	E. C. 1178	7	32
„	E. C. 1179	13	40
„	E. E. 1180	7	21
„	E. C. 1181	13	19
„	E. C. 1183	21	18
„	E. C. 1417	6	18
„	E. C. 1419	23	28

Inheritance:—This agglutinated pollen has proved to be a simple Mendelian recessive to the normal free and healthy pollen. A single factor named Y is responsible for the production of the free and healthy condition of the pollen grains. The history of the clans E. C. 214 and E. C. 288 are illustrative thereof and their behaviour is presented in Tables III and IV.



FREE POLLEN GRAINS.



AGGLUTINATED POLLEN GRAINS.

STERILITY.

TABLE III.

Clan No. E. C. 214.

(Segregation for the Fertility factor Y.)

——	Generation	Number	Characters	
			Fertile	Sterile
	Natural Cross 1924 (Y y)	..	Fertile	..
	F_2 . . .	E. C. 214 . . .	107	38
	F_3			
Genetic behaviour.		*Character of selection.*		
Segregating for Y . .	..	E. C. 771 Fertile . .	67	13
,, . .	..	E. C. 772 ,, . .	111	35
,, . .	..	E. C. 775 ,, . .	70	40
,, . .	..	E. C. 776 ,, . .	46	21
Pure for Y . . .	..	E. C. 773 ,, . .	Pure	..
,, . . .	..	E. C. 774 ,, . .	Pure	..
Absence of Y . .	..	E. C. 777 Sterile . .	..	Pure
,, . .	..	E. C. 778 ,, . .	..	Pure
	F_4 *(from E. C. 776 family—Y y).*			
Segregating for Y . .	..	E. C. 1146 Fertile . .	137	64
,, . .	..	E. C. 1147 ,, . .	104	37
,, . .	..	E. C. 1148 ,, . .	157	45
Absence of Y . .	...	E. C. 777 Sterile .	..	Pure
		E. C. 778 ,, .	..	Pure

TABLE IV.

Clan No. E. C. 888.

(Segregation for the fertility factor Y.)

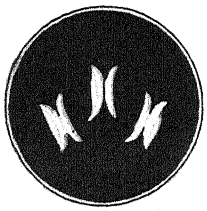
——	Generation	Number	Characters	
			Fertile	Sterile
	Natural Cross 1926 (Y y)	..	Fertile	..
	F_2	E. C. 888	167	44
Genetic behaviour.	F_3	*Character of selection.*		
Segregation for Y.	..	E. C. 1172 Fertile	111	27
,,	..	E. C. 1173 ,,	120	30
,,	..	E. C. 1174 ,,	121	23
,,	..	E. C. 1175 ,,	112	40
,,	..	E. C. 1176 ,,	98	32
,,	..	E. C. 1177 ,,	120	17
Absence of Y	..	E. C. 1178 Sterile	..	Pure
,,	..	E. C. 1179 ,,	..	Pure
,,	..	E. C. 1180 ,,	..	Pure
,,	..	E. C. 1181 ,,	..	Pure
,,	..	E. C. 1182 ,,	..	Pure
,,	..	E. C. 1183 ,,	..	Pure
	F_4 *(from E. C. 1172 and 1183—y y).*			
Absence of Y	..	E. C. 1415 Sterile	..	Pure
,,	..	E. C. 1416 ,,	..	Pure
,,	..	E. C. 1417 ,,	..	Pure
,,	..	E. C. 1183-*b* ,,	..	Pure
,,	..	E. C. 1183-*c* ,,	..	Pure

SUMMARY.

Chronic sterility, short of complete sterility, is occasionally met with in *Eleusine coracana*. The cause of this sterility is two-fold. It may be due to the non-dehiscence of anthers or to the agglutination and the consequent absence of free pollen. Normal dehiscence occurs with the presence of the X factor. Free pollen is produced by the Y factor. Both the factors X and Y behave as simple dominants to their absence resulting in sterility.

Eleusine coracana (Gaertn).

DEPTH OF GREEN IN PERICARP.



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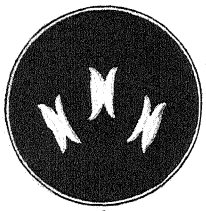

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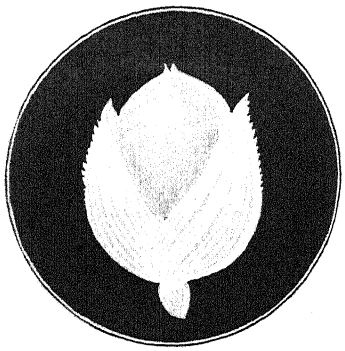

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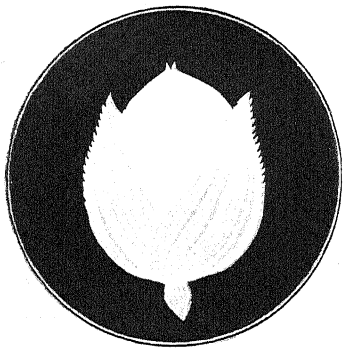

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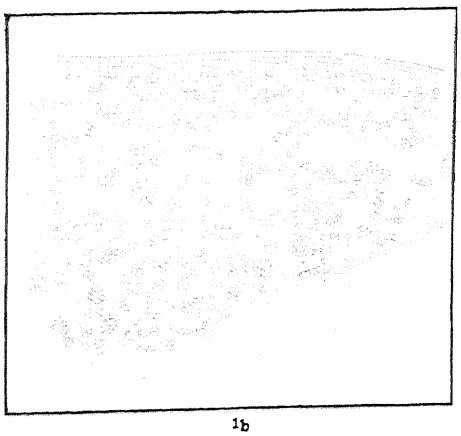

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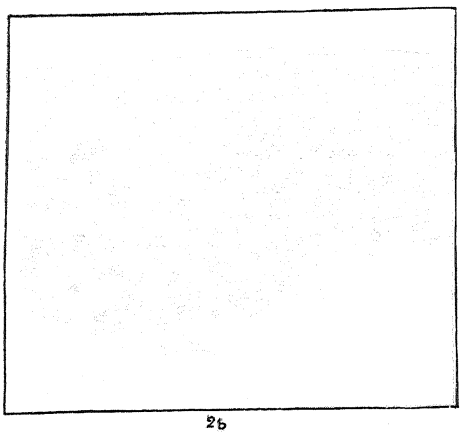

2b

GREEN

LIGHT GREEN

THE INHERITANCE OF CHARACTERS IN RAGI, *ELEUSINE CORACANA* (GAERTN.), PART IV.

DEPTH OF GREEN IN THE PERICARP.

BY

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(With Plate LXIV.)

INTRODUCTION.

Young growing grains of *ragi* have generally a green pericarp (Plate LXIV, No.1*a*.). This green colour shows itself while the grain is still young and enclosed within the glumes, and through the transparent tissues between the glumal veins it gives the earhead the characteristic green look in the early stages of flowering. The green of the pericarp continues to be present even after the growing grain passes the milky stage, when about a week after, it dries off into a thin, loose, greyish translucent and fairly persistent membrane enclosing the mature grain.

PERICARP TYPES AND ANTHER AFFINITIES.

In a few pure lines grown at the Millets Breeding Station, a variant of this pericarp green has been met with. This shows itself as a distinct light green pericarp which in the early stages gives a lighter tint of green even to the earhead (Plate LXIV, No. 2*a*.). The growing grain, when visible, presents a distinctly light green look, and in purple pigmented families this lightness and the quicker fading consequent on it gives the grains a pearly prominence against the purple-tinged glumes, which resulted in such heads being called "Bleached" in the early stages of the nomenclature of this character. This type can be identified even at the flowering phase from the ivory yellow colour of its dry anther mass as against the pale orange yellow of the green pericarp plants (Plate LXIV, Nos. 1 and 2). In purple-pigmented plants with purple-tinted anthers, this distinction shows itself also. Anthers borne on purple plants with green pericarp dry into a cinnamon drab colour. The same with a light green pericarp dry into a light cinnamon drab.

On a thorough examination, this character has resolved itself, shorn of its

collateral effects, into a simple differentiation in the depth of green in the pericarp of the young growing *ragi* grains. The pericarp is a tissue 5 to 7 cells thick containing a number of chloroplasts (Plate LXIV, Nos. 1*b* and 2*b*.). At the optimum stage, counts taken in the two types, show an average number of 14 chloroplasts per cell in the green pericarp, and 9 in the light green pericarp. The cells at the base contain a larger number than those at the sides or the top. The average diameter of chloroplasts in the green pericarp was found to be 7·6 μ and in the light green pericarp 5·5 μ.

Inheritance:—The green pericarp is traceable to the action of a single factor designated C_x in the absence of which the pericarp is reduced to light green. The following segregations in 7 families from natural crosses given in Table I bear this out.

TABLE I.

Pericarp—Green and Light Green.

Family No.	Segregation for	
	Green pericarp	Light green pericarp
E. C. 519	194	73
E. C. 520	206	77
E. C. 765	112	57
E. C. 767	154	47
E. C. 768	233	101
E. C. 769	244	62
E. C. 770	113	52
	1,256	469

The independence of the segregation for the depth of green in the pericarp of the growing seed of ragi from the plant purple pigmentation factors will be obvious from the behaviour of the F_2 of the following five of the above natural crosses, segregating for pigmentation in addition to pericarp green.

Family Nos.	F_2 Segregation.			
	Purple plant.		Green plant.	
	Green pericarp.	Light green pericarp.	Green pericarp.	Light green pericarp.
E. C. 765, 767, 768, 769, 770	658	241	208	78

In support of this conclusion the history of two other families E. C. 519 and E. C. 520 is given in the following tables (Tables II and III.)

TABLE II.

Clan E. C. 519.

Pericarp—Green and Light Green.

(Segregation for C_x and P.)

Generation	Number	Characters			
		Purple plant		Green plant	
		Green pericarp	Light green pericarp	Green pericarp	Light green pericarp
Natural Cross. (1925). (C_xc_xPp).		P. Plant. G. Pericarp.			
F_2	E. C. 519 . . .	132	50	62	23
F_3					
Genetic interpretation.	*Character of selection.*				
Segregating for C_x and P.	E. C. 845 P. Plant G. Pericarp.	118	30	31	12
,, .	E. C. 848 ,, .	98	35	30	6
Segregating for C_x— Pure for P.	E. C. 846 ,, .	112	48	..	..
Segregating for P— Pure for C_x.	E. C. 844 ,, .	133	..	63	..
,, .	E. C. 847 ,, .	168	..	48	..
,, .	E. C. 849 ,, .	161	..	51	..
Segregating for P— Absence of C_x.	E. C. 850 P. Plant L. G. Pericarp.	..	142	..	58
Pure for P— Absence of C_x.	E. C. 851 ,, .	..	Pure	..	..
,, .	E. C. 852 ,, .	..	Pure	..	..
Segregating for C_x— Absence of P.	E. C. 853 G. Plant G. Pericarp.	..	..	171	51
,, .	E. C. 854 ,, .	..	..	154	50
,, .	E. C. 835 ,, .	..	..	154	38
Absence of C_x and P. .	E. C. 856 G. Plant L. G. Pericarp.	..	..	..	Pure

TABLE III.

Clan E. C. 520.

Pericarp—Green and Light Green.

(Segregation for C_x and P.)

Generation	Number	Characters.			
		Purple plant		Green plant	
		Green pericarp	Light green pericarp	Green pericarp	Light green pericarp
Natural Cross. (1925). (C_xc_xPp).		P. Plant. G. Pericarp.			
F_2	E. C. 520 . . .	157	57	49	20
F_3					
Genetic interpretation.	*Character of selection.*				
Segregating for C_x and P.	E. C. 857 P. Plant . G. Pericarp .	111	26	42	15
,, .	E. C. 859 ,, .	115	45	30	11
Segregating for C_x— Pure for P.	E. C. 858 ,, .	150	56	..	..
,, .	E. C. 860 ,, .	143	43	..	..
Segregating for P— Pure for C_x.	E. C. 862 ,, .	147	..	55	..
Pure for C_x and P. .	E. C. 861 ,, .	Pure	..	..	..
Segregating for P— Absence of C_x.	E. C. 863 P. Plant . L. G. Pericarp .	..	137	..	48
,, .	E. C. 864 ,, .	..	131	..	54
,, .	E. C. 865 ,, .	..	144	..	45
Segregating for C_x— Absence of P.	E. C. 866 G. Plant . G. Pericarp .	..	..	155	46
,, .	E. C. 867 ,, .	..	..	144	46
,, .	E. C. 868 ,, .	..	..	136	71
Absence of C_x and P .	E. C. 869 G. Plant . L. G. Pericarp.	..	..	..	Pure

C_x is therefore independent of P. As has already been recorded [Rangaswami Ayyangar and Krishna Rao, 1931] the factor I induces differences of depth in P. To find out if this I working with P could have any possible connection with the C_x differentiating the green of the pericarp, a cross was designed and worked to the second generation. The results presented below (Table IV), show no connection whatever between C_x and I factors.

TABLE IV.

Independence of C_x to I factors.

Generation	Number	Characters			
		Purple plant		Localized purple plant	
		Green pericarp	Light green pericarp	Green pericarp	Light green pericarp
Artificial Cross (1927) . .	E. C. LIV .	..	..	..	..
Parents	E. C. 563 (C_xC_x PP. ii)	..	..	♀	..
,, ...	E. C. 851 (c_xc_x PP. II)	..	♂	..	..
F_1	(C_x c_x PP. Ii) .	F_1	..	..	..
F_2	E. C. 1311 .	112	55	47	8
	E. C. 1312 .	120	38	41	14
	E. C. 1313 .	134	46	49	14
		366	139	137	36
		X^2	=3·4	P	=·3

The experience from crosses which occurred in nature presented in tables I to IV has been put to a confirmatory test by artificially crossing E. C. 889, a purple pigmented plant with light green pericarp, with E. C. 995, a green-throughout plant with a green pericarp. The first generation of this cross No. LIX gave, as expected, a purple pigmented plant with a green pericarp, and an F_2 (E. C. 1470) segregating for all the expected four groups.

Grain Colour and pericarp Green :—It has been proved in a previous paper [Rangaswami Ayyangar, Krishna Rao and Wariar, 1931] that white ragi lacks

the B factors which make the grain brown. The effect of the C_x factor on a white grain, and any possible relationship with the white of the grain was sought to be proved by an artificial cross No. CL. between E. C. 1009 with a white grain and a green pericarp, and E. C. 869 with a brown grain and a light-green pericarp. The first generation gave as expected a green pericarp and brown grain. The second generation gave the expected independent segregation and it has been possible to extract a pure type (E. C. 2231) of white grain with light-green pericarp. This proves that C_x has no connection with the B factors.

Summary.

The pericarp of the developing grain of ragi is usually green. Minor races with a light-green pericarp are met with. A factor named C_x is responsible for the green of the pericarp. In its absence the pericarp is light-green. This is independent of P, I and B factors.

The tint of the dry anthers shows a differentiation in depth corresponding to the depth of green of the pericarp, and is associated with it.

References.

Rangaswami Ayyangar and Krishna Rao (1931). *Ind. J. of Agric. Science I, 434.*

Rangaswami Ayyangar, Krishna Rao and Wariar (1931). *Ind. J. of Agric. Science, I, 338.*

THE INHERITANCE OF CHARACTERS IN RAGI, *ELEUSINE CORACANA* (GAERTN.), PART V.

ALBINISM.

BY

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(With Plate LXV.)

In the year 1925 several single plant selections were taken from the variety Punasa Chodi of the Vizagapatam District. Of these, one selection E. C. 529 was noted in the seed-bed to have an admixture of many white seedlings. These were easily recognisable on the fifth day and showed best on the seventh day. The whites were characterised by poor growth and slow development both of shoot and root, many of them stopping with two leaves, while the greens of the same age had four. This poverty in growth tended to make them rather prostrate and be over-shadowed by the more vigorous greens. On the ninth day the leaf tips of the whites began to shrivel up and a day or two thereafter, the white seedlings started to die off.

From the surviving greens a crop was raised. From this crop, 60 individual plants were harvested separately and 60 germinations made. These germinations were done by spreading the seed separately on wet blotting paper, laid on to an inch of wet sand in a shallow zinc tray, 15 inches square. The seedlings though lean and drawn out were easily separable into greens and albinos about the fifth day and in this manner large masses of germinations could be quickly worked off.

Of the 60 germinated, 20 furned pure and 40 were noted to segregate and throw albinos—a remarkable coincidence to the theoretical ratio. The counts obtained from these 40 families are given below (Table I) and prove the existence in this family of a single factor difference between greens and albinos. This factor is designated C and in its absence the plants are incapable of developing chlorophyll.

TABLE I.

Clan E. C. 529-F_3.

Green and Albino seedling numbers in 40 segregating families.

Total population	Green seedlings	Albino seedlings	Ratio per 400
3,523	2,801	722	317 : 83
833	648	185	311 : 89
2,263	1,749	514	309 : 91
947	724	223	306 : 94
2,619	1,999	620	305 : 95
2,652	2,014	638	304 : 96
3,048	2,312	736	303 : 97
2,902	2,197	705	303 : 97
2,466	1,866	600	303 : 97
1,601	1,213	388	303 : 97
1,147	869	278	303 : 97
3,335	2,515	820	302 : 98
3,124	2,362	762	302 : 98
2,886	2,182	704	302 : 98
1,724	1,302	422	302 : 98
3,857	2,907	950	301 : 99
3,859	2,905	954	301 : 99
3,181	2,389	792	300 : 100
2,801	2,098	703	300 : 100
2,203	1,651	552	300 : 100
3,161	2,364	797	299 : 101
3,111	2,327	784	299 : 101
2,778	2,079	699	299 : 101
2,774	2,071	703	298 : 102
2,659	1,983	676	298 : 102
1,602	1,195	407	298 : 102
2,759	2,049	710	297 : 103
2,604	1,934	670	297 : 103

TABLE I—*contd.*

Clan E. C. 529-F_3.—contd.

Total population	Green seedlings	Albino seedlings	Ratio per 400
2,160	1,603	557	297 : 103
3,517	2,601	916	296 : 104
3,265	2,419	846	296 : 104
3,011	2,231	780	296 : 104
2,532	1,848	684	292 : 108
2,375	1,734	641	292 : 108
1,850	1,345	505	291 : 109
3,251	2,359	892	290 : 110
3,094	2,246	848	290 : 110
2,057	1,481	576	288 : 112
1,737	1,250	487	288 : 112
2,552	1,817	735	285 : 115
103,820	77,639	26,181	299 : 101
Theoretical Numbers.	77,865	25,955	300 : 100

A further stage in albino experience was met with in the year 1927 in family No. E. C. 835. The segregation of this family was noticed in the seed-bed and gave, when counted, 3782 greens and 263 whites. The poor number of whites stimulated further pursuit. 100 selections were carried forward to raise a third generation. It may be mentioned that this family was segregating for the "Pericarp Green" (C_x) factor [Rangaswami Ayyangar, Krishna Rao and Krishnaswamy, 1931] also. Of the 100 selections taken, 75 were from the "Green Pericarp" and 25 from the "Light Green Pericarp". The 100 selections were germinated and their behaviour is given below :—

—	Pure Greens	Green to Albino	
		15 : 1	3 : 1
Green Pericarp group (75)	32	23	20
Light Green Pericarp group (25)	11	7	7
	43	30	27
Theoretical ratio	7	4	4
$X^2 = \cdot 75$ $P = \cdot 7$			

It will be noticed that the pericarp character had no influence on this albino behaviour.

The detailed counts of the 30 families throwing albinos in the 15 : 1 ratio and the 27, giving a 3 : 1 ratio are presented in the following tables :—

TABLE II.

Clan E. C. 835-F_3.

27 families segregating—3 : 1 ratio.

Total population	Green seedlings	Albino seedlings	Ratio per 400
1,331	1,075	256	323 : 77
1,181	943	238	319 : 81
1,811	1,439	372	318 : 82
1,189	945	244	318 : 82
1,411	1,117	294	317 : 83
1,197	949	248	317 : 83
1,131	886	245	313 : 87
1,481	1,149	332	310 : 90
1,315	1,019	296	310 : 90
1,174	901	273	307 : 93
1,160	891	269	307 : 93
775	593	182	306 : 94
2,402	1,830	572	305 : 95
1,225	934	291	305 : 95
1,125	859	266	305 : 95
899	684	215	304 : 96
1,459	1,104	355	303 : 97
1,088	825	263	303 : 97
1,713	1,292	421	302 : 98
1,696	1,282	414	302 : 98
1,202	909	293	302 : 98
913	689	224	302 : 98

TABLE II—*contd.*

Clan E. C. 835-F_3.

27 families segregating—3 : 1 ratio—*contd.*

Total population	Green seedlings	Albino seedlings	Ratio per 400
1,093	823	270	301 : 99
746	559	187	300 : 100
1,121	837	284	299 : 101
970	724	246	299 : 101
1,012	752	260	297 : 103
33,820	26,010	7,810	307 : 93
Theoretical Numbers.	25,365	8,455	300 : 100

TABLE III.

Clan E. C. 835-F_3.

30 families segregating—15 : 1 ratio.

Total population	Green seedlings	Albino seedlings	Ratio per 1,600
949	907	42	1,529 : 71
1,518	1,447	71	1,525 : 75
2,180	2,076	104	1,524 : 76
873	830	43	1,521 : 79
1,094	1,039	55	1,520 : 80
1,037	983	54	1,517 : 83
953	903	50	1,516 : 84
1,108	1,049	59	1,515 : 85
1,785	1,687	98	1,512 : 88
1,025	967	58	1,509 : 91
1,546	1,457	89	1,508 : 92
1,005	947	58	1,508 : 92
969	913	56	1,508 : 92
1,503	1,416	87	1,507 : 93
1,314	1,238	76	1,507 : 93

TABLE III—*contd.*

Clan E. C. 835-F_3.

30 families segregating—15 : 1 ratio—*contd.*

Total population	Green seedlings	Albino seedlings	Ratio per 1,600
1,218	1,147	71	1,507 : 93
1,204	1,133	71	1,506 : 94
1,062	999	63	1,505 : 95
996	935	61	1,502 : 98
1,204	1,129	75	1,500 : 100
1,093	1,025	68	1,500 : 100
1,223	1,146	77	1,499 : 101
1,170	1,094	76	1,496 : 104
1,627	1,520	107	1,495 : 105
777	726	51	1,495 : 105
772	721	51	1,494 : 106
1,200	1,119	81	1,492 : 108
724	675	49	1,492 : 108
553	515	38	1,490 : 110
939	868	71	1,479 : 121
34,621	32,611	2,010	1,506 : 94
Theoretical Numbers.	32,457	2,164	1,500 : 100

It will thus be evident that not one, but two factors are responsible, either independently or conjointly, in the production of green in a seedling. These chlorophyll factors have been called C_1 and C_2.

As has been mentioned already Clan E. C. 835 was segregating for the "Green Pericarp" factor, giving both green and light green pericarps. From the F_3 of this Clan, presented in Table II, homozygous greens of both kinds of pericarp were isolated for crossing with each other. These homozygous ones being either $C_1C_1c_2c_2$, or $c_1c_1C_2C_2$, a series of intercrosses were done with a view to put together C_1 and C_2 and bring out a later segregation of a dihybrid type, in which the absence of both will yield albinos. In this work pericarp green segregation came in very handy to spot out the success or otherwise of a cross even in the F_1 stage. The mothers were Light Greens and the male parent was a green pericarp. All F_1s that gave a green pericarp could thus be set down to be successful crosses.

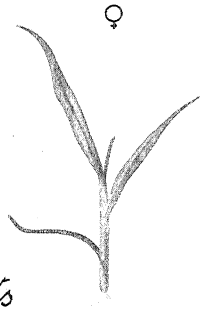
Elevsine coracana (Gaertn)

ALBINISM

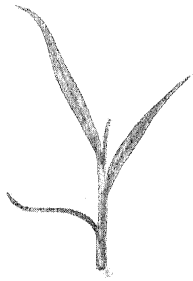
Cross No. CLVII

♀ ♂

Parents

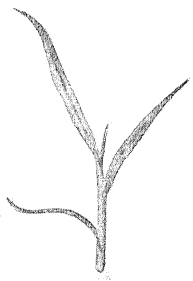


$C_1C_1c_2c_2$



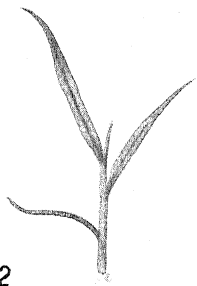
$c_1c_1C_2C_2$

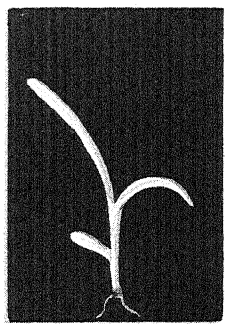
F_1



$C_1c_1C_2c_2$

F_2





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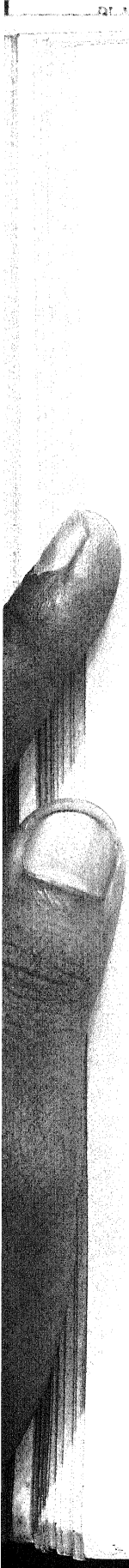

The following parents extracted from the segregations of Table II. were used :—

♀ Light Green Pericarp	E. C. 1568
	E. C. 1570
	E. C. 1571
	E. C. 1572
♂ Green Pericarp	E. C. 1567

The behaviour of the crosses is given in Table IV.

TABLE IV.

Clan E. C. 835.

Artificial Crosses to induce Albinism.

Cross No.	Parents Extracted types for C_1 or C_2.		No. of F_1 plants.	F_2 Behaviour	
				Green.	White.
E. C. CLVI	♀ E. C. 1572	♂ E. C. 1567	3	All	
				All	
				All	
E. C. CLIX	E. C. 1568	,,	6	All	
				All	
				All	
				All	
				All	
				All	
E. C. CLVII	E. C. 1570	,,	8	162	11
				514	36
				340	22
				398	26
				840	59
				298	18
				702	47
				641	39
E. C. CLVIII	E. C. 1571	,,	3	479	24
				261	16
				167	10
Total of F_2 segregates .				4,802	308

In the above table the male parent E. C. 1567 and the mothers E. C. 1570 and E. C. 1571 figuring in crosses CLVII and CLVIII have produced F_1 plants capable of throwing albinos in the F_2. Taking it that E. C. 1567 had the C_1 factor, it will follow that E. C. 1570 and E. C 1571 had the duplicate factor C_2. It has thus been possible to isolate green types culpable of producing albinos on mating.

Summary.

Two factors C_1 and C_2 either alone or together are responsible for the production of chlorophyll in the plant. In the absence of both the resulting seedling turns white and dies. Plants with C_1 and C_2 have been isolated and crossed with the result that in the F_2 they segregated and threw albinos one in sixteen.

The factor C_x inducing a differential depth in the pericarp has no influence whatever on C_1 or C_2.

REFERENCE.

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INHERITANCE OF COROLLA COLOUR IN SOME INDIAN COTTONS.

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Introduction.

Several investigations have been published reporting the mode of inheritance of some characters in cotton. Kearney [1930] has recently surveyed the present knowledge of inheritance of such characters about which more or less convincing evidence of monohybrid or dihybrid inheritance has been adduced. The manner of inheritance of still other characters is as yet rather obscure and even in the case of those that have been rather carefully studied, a definite alternative manner of inheritance has not been found excepting in a very small number of cases. In the case of quantitative characters, the expression of a great number of them occurs in degree of magnitude rather than as qualitative classes and F_2 frequency distributions give unimodal curves, rendering interpretation difficult. Even in the case of a comparatively simple factor like petal spot, there is no unanimity of opinion and an explanation has been advanced that that is because crosses have been usually made between different species, complicating the issues.

There have been under investigation for the past four or five years at Dharwar a few species crosses involving red anthocyanin pigmentation of the corolla. The mode of inheritance of this character has been found to be due to a simple Mendelian factor in one case and to two factors in the other cases under study. In spite of the fact that different species were involved in the crosses, the inheritance was surprisingly clear-cut and it was thought worth while to publish the data.

Previous investigations.

Previous work on the inheritance of corolla colour has been recently reviewed by Kearney in the paper referred to above, and also by Harland [1929]. A repetition is therefore unnecessary. Fletcher [1907] and Leake [1911] have however reported on the inheritance of red corolla colour in cotton plants and their work is therefore briefly noticed here.

Fletcher reported in 1907 the result of crossing a red-flowered Indian cotton with a yellow-flowered variety. In the F_1 generation equal numbers of reds and yellows were obtained while in the F_2 generation, there was considerable confusion. Balls [1908] has suggested that Fletcher's material was heterozygous and that seems to be a correct diagnosis.

The work of Leake [1911] was more convincing and elaborate. His crosses involved types that had red, yellow, and white flowers. Both in his red-yellow-flowered cross and red-white-flowered cross, the F_1 generation reaction was according to him intermediate. In the subsequent progenies he states that red corolla colour was inherited on the basis of a 3 : 1 ratio in the case of the former (red yellow) cross and on the basis of a 9 : 3 : 3 : 1 ratio in the case of the latter cross.

Materials.

The following species of *Gossypium* were used as parent material in the crosses :—

Gossypium sanguineum Hassk. is a cotton having flowers with red-coloured corolla. It is usually grown in the Punjab and has been in cultivation on the Dharwar Farm for the past ten years. In all the crosses it was used as the male parent.

G. herbaceum L. is a yellow-flowered cotton and the variety used in the crosses is a selection known locally as Dharwar 1 cotton.

G. neglectum var *rosea* G. is a white-flowered variety from the Berar and the Central Provinces. The other white-flowered variety was *G. neglectum* sub var. *cutchica* G.

All the above cottons have been described by Gammie [1907]. Highly inbred material of all the four species was used in the crosses. The method of selfing has been described by the senior author [1923] in a previous publication. So far as the flower colour is concerned, there is not any doubt regarding the homozygosity of the parents.

The plants for crossing purposes were selected in the morning, and after

emasculation of the ovule parents, both they and the pollen parent flowers were bagged. Crossing operation was done in the afternoons on the same day and the crossed flowers were protected by bagging for a period of 3 to 4 days. In later progenies the flowers were merely 'selfed.'

Results.

G. herbaceum × *G. sanguineum*:—A cross with *G. herbaceum* which has yellow-flowered petals, as the female parent and *G. sanguineum* as the male parent was made in 1926. For the study of the F_1 generation, about 100 plants were available. The corolla colour in this generation was red but it was not the deep red colour of the parent. That there was some dilution of colour was evident. In the year 1928, the F_2 generation was grown and 498 plants were available for study. The segregation for corolla colour occurred in the manner shown in Table I.

Table I.

Segregation of 498 F_2 plants for corolla colour compared with calculated numbers for 3:1 ratio.

Phenotype	Observed	Calculated	Deviation	Dev./P.E.
Red . . .	372	373·5	1·5	0·23
Yellow . . .	126	124·5	..	..

The observed figures and calculated ones show good fits. Though there was dilution of red colour in the F_1 generation, the F_2 segregation is in a 3 : 1 ratio, showing dominance of red pigmentation. The cross was not further studied.

G. neglectum sub. var. *cutchica* × *G. sanguineum*:—This cross was made in the year 1925. The white-flowered parent was the female and the red-coloured *sanguineum* parent was the male. There were nearly 100 plants in the F_1 generation for study. The corolla colour was not like that of the parent in this case also, and some dilution of the pigment was again apparent.

In the F_2 generation there were only 145 plants but the segregates were red, pink, yellow and white. The pink colour was not like that of the F_1 generation colour reaction, which in comparison seemed to be distinctly redder. The figures obtainedare given in Table II.

TABLE II.

Segregation of 145 F_2 plants for corolla colour compared with calculated numbers for 9:3:3:1 ratio.

Phenotype	Observed	Calculated	O—C	$\frac{(O - C)^2}{C}$
Red . . .	84	82	2	·487
Pink . . .	27	27	0	—
Yellow . . .	26	27	—1	·037
White . . .	8	9	—1	·111
			Total .	·635

$X^2=0.635$

Values of p when X^2 is less than one are not given, but theory and observation in the above case could hardly agree more perfectly. There are thus two factor pairs involved in this cross.

F_3 generation data yielded results further testing the hypothesis. In Tables III and IV the inheritance of corolla colour of plants selected in the F_2 generation are given.

TABLE III.

Segregation of 97 F_3 plants for corolla colour compared with calculated numbers for 10:6 ratio.

Phenotype	Observed	Deviation	Dev./P. E.
Red	47		
Pink	26	..	
Yellow . . .	18	7·25	2·3
White . .	6	..	

As only two genotypes deviated from the calculated numbers, the X^2 test was not applied. Instead the reds and whites were added together, as also the pinks and yellows. The departure of these observed figures from the calculated ones on the basis of a 10:6 ratio was determined, and after finding the probable error,

whether the deviation was a significant or an insignificant one was noted. The deviation was not very significant, odds being 7·28 to 1.

TABLE IV.

Segregation in F_2 generation for corolla colour compared with calculated numbers for 3:1 ratio and of F_3 plants that bred true.

F_2 Plant No.	F_2 Phenotype	F_3 Phenotypes				Dev.	Dev./P.E.
		Red	Pink	Yellow	White		
147	Red . . .	92	..	...	..	...	..
51	Pink . . .	..	93	...	..	..	..
14	Yellow . .	..	..	91	..	..	..
30	Yellow . .	..	..	87	..	..	..
101	White . .	..	..	..	77	...	..
135	White . .	..	..	...	78	...	..
137	White . .	..	..	..	95	...	..
28	Red . . .	70	14	..	..	7	2·6
54	Red . . .	64	18	..	..	2·5	1·3
22	Pink . .	..	63	..	29	6	2·1
36	Pink . .	..	55	..	19	·5	.2
65	Pink . .	..	77	..	22	2·8	.9
160	Pink . .	..	65	..	26	3·3	1·1
	Yellow . .	..	..	59	21	1	.4
	Yellow . .	..	...	70	25	1·3	.3
	Yellow . .	..	..	74	23	1·3	.4

The F_3 generation data further demonstrated that red-petalled flowers when crossed with white-flowered ones were inherited in a dihybrid ratio. A few F_2 phenotypes, red, pink, yellow and all whites, bred true as is to be expected.

G. neglectum var. *rosea* × *G sanguineum* :—This cross was also made in the year 1925. The white-flowered parent was again the female. In the F_1 generation the red colour of the corolla showed dilution as in previous cases. The F_2 segregation is given in the Table V.

TABLE V.

Segregation of 96 F_2 plants for corolla colour compared with calculated numbers for 10:6 ratio.

Phenotype	Observed	Deviation	Dev./P.E.
Red	46	....	.....
Pink	28	....	....
Yellow	16	8	2·5
White	6	....	....

Here, again, instead of applying the X^2 test, the segregates were grouped on a 10:6 ratio basis by adding the reds and the whites together and the pinks and yellows together and noting the deviation from expected figures. In the F_2 generation there were several seedling deaths due to *Fusarium* wilt. This method of finding the goodness of fit for ratios segregating in more than two classes, while not being very accurate, accounts for differential viability, etc., and was useful in this case because of the seedling disease.

For the F_3 generation tests only pink, yellow and white-flowered plants alone were available. The results are tabulated in Table VI.

TABLE VI.

Segregation of F_3 generation for corolla colour compared with calculated numbers for 3 :1 ratio and F_3 plants that bred true.

F_2 plant No.	F_2 Phenotypes	F_3 progeny			Dev.	Dev./ P. E.
		Pink	Yellow	White		
58	Pink	92	..	...	Breeds true.	
27	White	..	..	81	Breeds true.	
45	White	..	...	82	Breeds true.	
66	Pink	59	..	24	3·25	1·2
116	Pink	47	..	17	1·00	0·4
21	Yellow	..	50	15	1·25	0·5
71	Yellow	...	67	24	1·25	0·4
73	Yellow	..	60	19	0·75	0·3

F_3 progeny bred in a manner which is in conformity with assumed hypothesis. Departures of observed figures from expected ones were on the whole not significant.

Discussion.

The mode of inheritance of corolla colour in cottons is found to be a comparatively simple matter. Inheritance was clear-cut and unambiguous even though different species were concerned in the crosses. The red colour of the corolla is due to an anthocyanin pigment and it appears to be dominant over yellow and white colours, even though slight dilution of red colour takes place, in the F_1 generation.

The following factorial hypothesis is suggested:
RR=pink colour of corolla; rr=White colour;
YY=Yellow colour of corolla; yy=White colour.

From the data it can be concluded that the presence of both R and Y is necessary for the expression of the red colour in the petals. R alone gives pink colour and Y alone gives yellow colour. The genotypic composition of the parents would then be :—

G. sanguineum=RRYY,
G. herbaceum=rrYY,
G. n. rosea=rryy,
G. n. r. cutchica=rryy.

The F_2 genotypes and their breeding behaviour in the F_3 generation for the cross *G. n. rosea G. sanguineum* would be as follows :—

F_2 genotypes	Parts of 16	Breeding in F_3 as :—
RRYY (red) . . .	1	Breeds true.
RRYy (red) . . .	2	3 red : 1 pink.
RrYY (red) . . .	2	3 red : 1 yellow.
RrYy (red) . . .	4	9 red : 3 pink : 3 yellow : 1 white.
RRyy (pink) . . .	1	Breeds true.
Rryy (pink) . . .	2	3 pink : 1 white.
rrYY (yellow) . .	1	Breeds true.
rrYy (yellow) . .	2	3 yellow : 1 white.
rryy (white) . . .	1	Breeds true.

It may be stated here that Gammie [1907] has described a variety occurring in nature which has pink flowers and which he calls *G. sanguineum* var. *minor*.

Even in the case of the inheritance of yellow pigmentation of corolla there does not seem to be much complication. The senior author in a previous publication has published data of a cross where he used the same yellow-coloured and white-coloured parents as were used in these crosses. He then divided the F_2 segregation into three classes, full-yellow, pale-yellow and white. That the pale-yellow colour was merely a case of dilution of colour due to the presence of two factors for white, rr and yy, is evident from the study of the crosses reported in this paper. The segregation of yellow colour was on the basis of a 3:1 ratio as shown in Table VII.

TABLE VII.

Segregation of 1057 F_2 plants as to corolla colour compared with calculated numbers for 3:1 ratio.

Phenotype	Observed	Deviation	Dev./P. E.
Yellow . . .	805	...	..
White . . .	252	12·25	1·3

The explanation furnished by Harland [1929] that inheritance is on the basis of 39:9:16, while being very attractive, is not tenable from the data presented in this paper.

The data presented in this paper further confirms Leake [1911] whose conclusions regarding inheritance of red corolla colour was the same as arrived at here.

SUMMARY.

1. Crosses were made in 1925 and 1926 between white-flowered and red-flowered and yellow and red-flowered cotton plants.

2. In the F_1 generation, the colour of the corolla was red, though the intensity was not as much as that of parent, some dilution of colour being apparent.

3. In the case of the yellow-flowered and red-flowered plants segregation in the F_2 was according to the simple Mendelian ratio, 3:1.

In the case of the white flowered and red flowered plants segregation was on the basis of 9:3:3:1 ratio.

4. F_3 segregation further proved the assumed hypothesis.

5. Harland's explanation that yellow flower colour is inherited on the basis of 39:9:16 ratio, involving 3 factor pairs does not seem to be tenable from the data obtained in the crosses herein reported.

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THE INHERITANCE OF CHARACTERS IN *SETARIA ITALICA* (BEAUV.) THE ITALIAN MILLET, PART I.

GRAIN COLOURS.

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(With Plate LXVI.)

Setaria italica, the Italian Millet, is a small-grained cereal grown extensively in India. It covers an area of about one and a half million acres in the Madras Presidency and is grown in close association with cotton.

This cereal has been under study at the Millet Breeding Station from the year 1925, and this paper records one portion of the progressed work, namely, the nature of the various grain colours, their inter-relationships and inheritance.

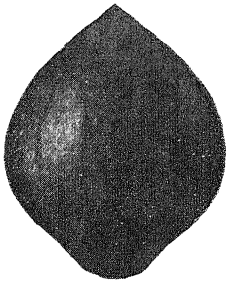
In the grain of this millet the rice is enclosed by a glistening husk of thickened fourth glume and palea. This husk takes on varying colours, and gives rise to the many varieties of grain met with. The commonest colour is a Buff, designated, by its characteristic association with this millet, Korra Buff, after *korra*, the Telugu name of this cereal. This name has been adopted to introduce the basic individuality of this Buff. Including this Buff the following six colours were met with and studied :—Black, Sepia, Tawny Buff, Korra Buff, Red and Tawny Red. (Plate LXVI.) These six colours fall into the two groups Blacks and Non-blacks. In the latter are the four colours, Tawny Buff, *Korra* Buff, Red and Tawny Red. These four colours fall into the following two pairs :—

Tawny Buff and Red.
Korra Buff and Tawny Red.

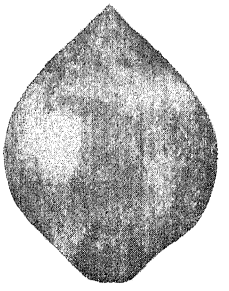
Korra Buff and Tawny Red are the lighter shades and with the addition of a factor I are intensified into Tawny Buff and Red respectively. The starting point

SETARIA ITALICA (*Beauv*)

GRAIN COLOURS

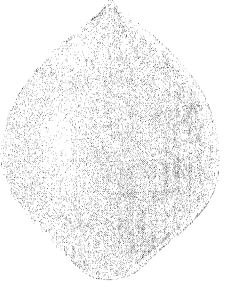


Black

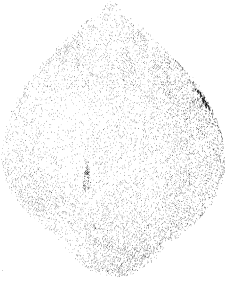


Sepia

Tawny Buff

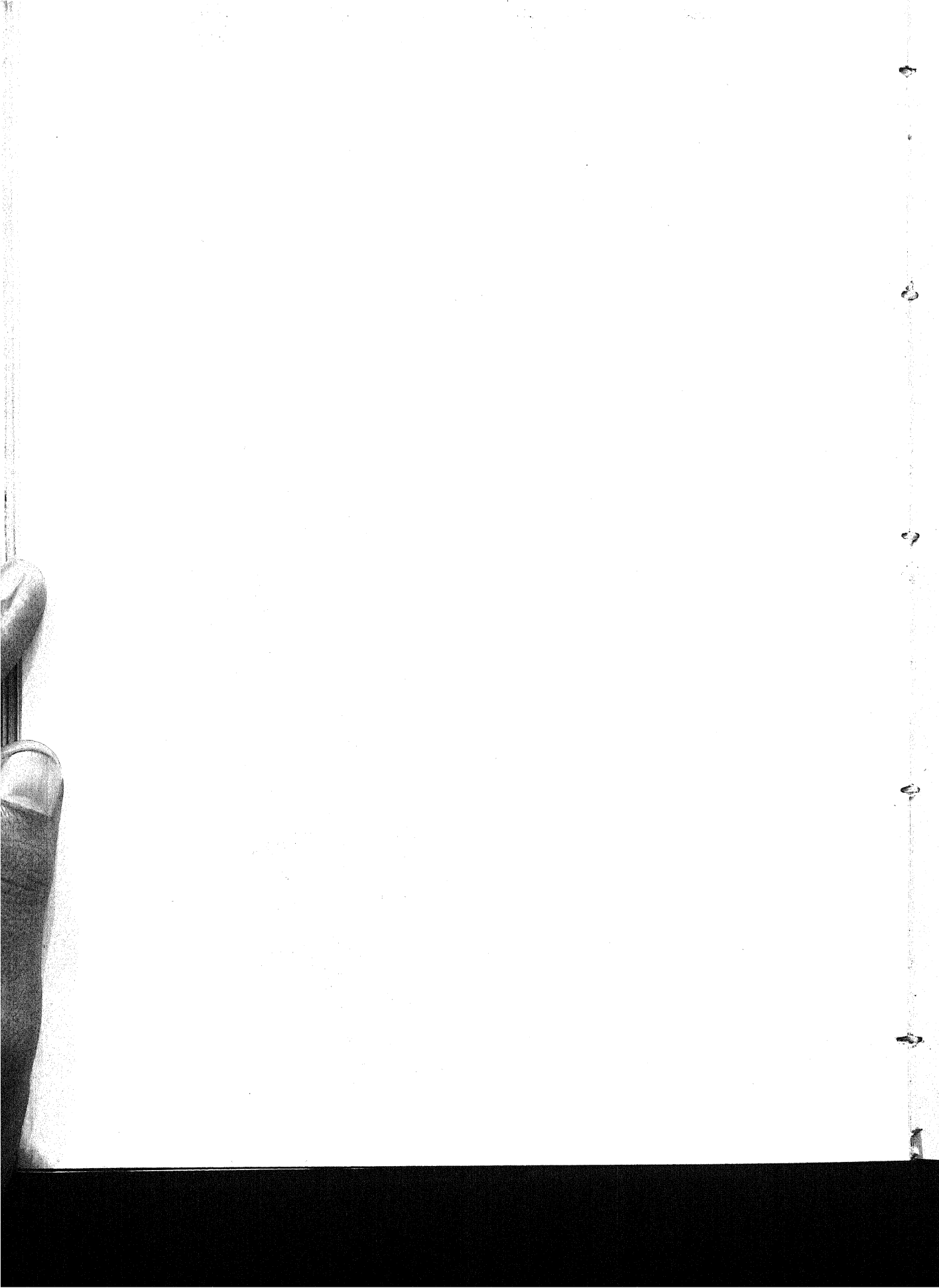


Red



Korra Buff

Tawny Red



for this colour scheme is therefore Tawny Red. To this colour the addition of a factor K (after Korra) makes it Korra Buff.

On this Non-black group, a third factor B operates to form the Black group. This B factor shows its blackening effects only in the presence of the I factor, for example, Red with the B factor turns into Sepia and Tawny Buff with the B factor turns into Black. The basic colours Tawny Red and Korra Buff could, however, carry the factor B, but would require the activating effect of I to manifest the presence of this factor in them.

With the coming in of the K factor the colour schemes have two starting points with the basic difference that in the first one Tawny Red, the factor K is absent and in the other one Korra Buff, the factor K is present. This basic difference groups the colours as follows :—

With K.	*Without K.*
Black.	Sepia.
Tawny Buff.	Red.
Korra Buff.	Tawny Red.

The interaction of K, I and B factors in this general scheme is graphically presented in the following structural formula.

Black	=	K	+	Sepia
‖				‖
B				B
+				+
Tawny Buff	=	K	+	Red
‖				‖
I				I
+				+
Korra Buff	=	K	+	Tawny Red.

The following tables present data in support of the above interpretation.

The first set of tables (Tables I, II, III) pertains to the non-black group and deals with the four colours, Tawny Buff, Korra Buff, Red and Tawny Red. For a casual look, in any family segregating for all these four colours, Red will be the only outstanding colour, easily singled out. Next to Red, Korra Buff is separable. The confusion will be in the separation of Tawny Buff from Tawny Red. Some of the Tawny Buffs are easily mistaken for Korra Buff. Weather, and the particular stage of ripeness at which to read off the character, have some influence on the ease with which the groups are made. Often, bristles and worse, segregates among bristles, tend to add to the confusion. These difficulties notwithstanding, after a little practice, separation is fairly easy. Anyway, more generations and the possi-

bility of simplifying the segregates, coupled with crosses between extracted pure lines, leave absolutely no doubt as to the individuality of the shades leading to possible confusion. This aspect is stressed here to account for the absence of figures in the Tawny Red column of some of the F_2s. It took a generation more to single out the doubtful groups.

The experience of a 12:3:1 ratio of Orange, Red and Yellow grains recorded by Syuiti Saito [1923] where 'Orange' and 'Yellow' were often scarcely distinguishable, would seem to correspond to the 9:3:3:1 dihybrid experience detailed below, where Orange embraces our Tawny Buff and Korra Buff, and Yellow stands for our Tawny Red.

TABLE I.

Pure for absence of B. Segregating for K and I.

Generation	Family No.	Grain Colours			
		Tawny Buff bbIIKK	Korra Buff bbiiKK	Red bbIIkk	Tawny Red bbiikk
Natural Cross.					
F_2	S. I. 842	193	55	57	26
F_3					
Character of Selections.					
Tawny Buff . .	S. I. 1,439 1440, 1441, 1444, 1445, 1446, 1447, 1449, 1450 (bbIiKk).	1122	315	277	95
,, ,, . .	S. I. 1448 (bbIiKK) . .	143	45	..	..
,, ,, . .	S. I. 1442, 1443 (bbIIKk) .	260	..	75	..
Korra Buff . .	S. I. 1451, 1452, 1453, 1454, (bbiiKk).	..	609	..	142
Red . . .	S. I. 1456 (bbIikk) . .	..	..	360	102
,, . . .	S. I. 1455, 1457, 1458, (bbIIkk).	..	..	pure	..
Tawny Red . .	S. I. 1459, 1460 (bbiikk) .	..	..	..	pure

TABLE II.

Pure for absence of B. Segregating for K and I.

Generation	Family No.	Grain Colours.			
		Tawny Buff bbIIKK	Korra Buff bbiiKK	Red bbIIkk	Tawny Red bbiikk
Natural Cross (1926).					
F_2	S. I. 291	55	16	15	?
F_3					
Character of Selections.					
Tawny Buff . .	S. I. 892, 894 (bbIiKk). .	351	163	116	41
„ „ . .	S. I. 897 (bbIiKK) . .	301	79	..	..
„ „ . .	S. I. 895, 896 (bbIIKk). .	623	..	154	..
„ „ . .	S. I. 891, 893 (bbIIKK) .	Pure	..	..	..
Korra Buff . .	S. I. 898 (bbiiKk) . .	..	198	..	66
Red . . .	S. I. 887, 889, 890 (bbIikk) .	..	..	846	308
„ . . .	S. I. 888 (bbIIkk) . .	..	..	Pure	..
F_4 (from S. I. 897)—					
Tawny Buff .	S. I. 1501, 1503 . . .	Pure	..	..	..
„ „ . .	S. I. 1502, 1504 . . .	317	96	..	..
Korra Buff .	S. I. 1505	..	Pure	..	—
F_4 (from S. I. 895)—					
Tawny Buff .	S. I. 1493, 1495, 1496 . .	Pure	..	..	..
„ „ .	S. I 1494	86	..	16	..
Red . . .	S. I. 1497, 1498, 1499, 1500 .	..	..	Pure	..
F_4 (from S. I. 898)—					
Korra Buff .	S. I. 1507	..	Pure	..	..
„ „ . .	S. I. 1506, 1508, 1509 . .		145	..	30
Tawny Red .	S. I. 1510	..	..	..	Pure

TABLE III.

Pure for absence of B. Segregating for K and I.

Generation	Family No.	Grain Colours			
		Tawny Buff bbIIKK	Korra Buff bbiiKK	Red bbIIkk	Tawny Red bbiikk
Natural Cross (1926).					
F_2	S. I. 290	78	19	15	?
F_3					
Character of Selections.					
Korra Buff . .	S. I. 877, 878 (bbiiKK). .	..	Pure	..	..
,, ,, . .	S. I. 879, 883 (bbiiKk). .	..	433	..	104
Red . . .	S. I. 880, 881, 885 (bbIIkk) .	..	..	Pure	..
,, . . .	S. I. 882, 884, 886 (bbIikk) .	..	..	789	211
Natural Cross (1926).					
F_2	S. I. 743	111	44	53	?
F_3 Red . . .	S. I. 1010, 1012, 1014, 1017, 1019 (bbIIkk).	..	..	Pure	..
,, . .	S. I. 1009, 1011, 1013, 1015, 1016, 1018 (bbIikk).	..	..	1079	372
Natural Cross (1928).					
F_2	S. I. 1351	117	39	32	11

From a study of the foregoing tables, it will be clear that two factors are at work in the segregations involving Tawny Buff, Korra Buff, Red and Tawny Red.

To confirm the experiences derived from the above natural hybrids an artificial cross was made between a Korra Buff (bbiiKK) S. I. 1256, and a Red (bbIIkk) S. I. 1200, and true to expectations gave rise to (23) hybrids with Tawny Buff grains (bbIiKk). From these, four heads S. I. 1882 to 1885 were sown in summer 1931 and segregated for Tawny Buff, Korra Buff, Red and Tawny Red with a total population of 753, 400, 313 and 125 respectively.

We now come to the Black group. As already indicated the Blacks consist of two shades Black and Sepia. Sepia with the K factor produces Black. The Sepia and the Black are not easily separable to begin with, but with a little experience this could be done. The Sepia represents the B factor superimposed on Red. In immature grains of Sepia, the red back-ground underneath the black wash serves to mark the Sepia out. In the Blacks a similar immaturity shows out on a Buff background.

The following table (Table IV) presents a family No. S. I. 874, segregating for this factor K only.

TABLE IV.

Pure for B and I. Segregating for K.

Generation	Family No.	Grain Colours	
		Black BBIIKK	Sepia BBIIkk
Natural Cross (1928)			
F_2	S. I 874	195	67
F_3 *Character of Selections*			
Black . . .	S. S. 1185 (BBIIKK)	Pure	..
,, . . .	S. I. 1186 to 1196 (BBIIKk) . . .	1966	600
Sepia . . .	S. I. 1197 & 1198 (BBIIkk) . . .	..	Pure
F_4 (from S. I. 1195)—			
Black . . .	S. I. 1781 to 1784 (BBIIKk) . . .	923	317
Sepia . . .	S. I. 1785 (BBIIkk)	..	Pure

The next table (Table V) presents a clan pure for B and K factors and segregating for the I factor.

TABLE V.

Pure for B and K. Segregating for I.

Generation	Family No.	Grain Colours	
		Black BBIIKK	Korra Buff BBiiKK
Natural Cross (1922)			
F_2	S. I. 109	10	2
F_3 *Character of Selections*			
Black . . .	S. I. 216 to 219 (BBIiKK) . .	508	150
Korra Buff . .	S. I. 220, 221 (BBiiKK) . . .	..	Pure
F_4 (from S. I. 219)—			
Black . . .	S. I. 367, 369 (BBIIKK) . .	Pure	..
,, . . .	S. I. 365, 366, 368, 370 (BBIiKK) .	154	47

In the next set of tables the families are pure for the K factor and segregate for the B and I factors. When pure for K, the expressions of the I factor are not so definite, with the result that the separation of Tawny Buff and Korra Buff is very difficult. On this account till the F_3 stages of this experience, in the segregates Black : Tawny Buff : Korra Buff instead of the 9 : 3 : 4, the separation partook of the surer 9 : 7 ratio of Blacks to Buffs (Tables VI and VII).

The segregation of grain colours into Buff, Yellow and Black in the ratio of 1 : 1·4 : 3·2 noted by Woodhouse and Ghosh [1911] could be fitted into these experiences, their Buff and Yellow corresponding to Tawny Buff and Korra Buff of these tables.

TABLE VI.

Pure for K. Segregating for B and I.

Generation	Family No.	Grain Colours			
		Black BBIIKK	Tawny Buff bbIIKK	Korra Buff	
				BBiiKK	bbiiKK
Natural Cross (1926) F_2 . . .	S. I. 287	39	34		
F_3 *Character of Selections*— Black . .	S. S. 865, 867 (BBIIKK) .	Pure	..		
,, . .	S. I. 864, 866 (BbIiKK) .	275	218		
Korra Buff .	S. I. 868, 869 . . .	..	All		
F_4 (from S. I. 864)— Black . .	S. I. 1473, 1486 (BBIIKK) .	Pure	..		
,, . .	S. I. 1468, 1471, 1472, 1474, 1475, 1477, 1478, 1480, 1483, 1484, 1485, (BbIiKK) . . .	996	794		
,, . .	S. I. 1467, 1469, 1470, 1476, 1479, 1481, 1482, (BBIiKK) . . .	759	272		

TABLE VII.

Pure for K. Segregating for B and I.

Generation	Family No.	Grain Colours			
		Black BBIIKK	Tawny Buff bbIIKK	Korra Buff	
				BBiiKK	bbiiKK
Natural Cross (1926) F_2	S. I. 286 . . .	50	41		
F_3 *Character of Selections*— Black . .	S. I. 844, 845, 847, 849, 851, (BbIiKK) . . .	630	523		
,, . .	S. I. 846 (BbIIKK) . .	212	88		
,, . .	S. I. 843, 848 (BBIiKK) .	333	..		137
Non-blacks .	S. I. 852 to 863 . . .	..	All		

The separation of the Buffs and the artificial production of Black by crossing Buffs was attempted by making intercrosses between Buffs of families S. I. 858, 859, 860, 861, 862, 863, and 868 and 869, of the three inseparable genetic compositions bbIIKK, BBiiKK, and bbiiKK, according to the following scheme with the results noted against each.

S. I. Cross No.	Parents	F_1	No. carried forward to F_2
XIII	S. I. 858 × S. I. 859	All Buffs	..
XIV	„ × S. I. 860		
XV	„ × S. I. 861		
XVI	„ × S. I. 862		
XVII	„ × S. I. 863		
XVIII	„ × S. I. 868		
XIX	„ × S. I. 869		
XXV	S. I. 859 × S. I. 868	17 Blacks	6
XXX	S. I. 860 × S. I. 868	25 „	..
XXXIII	S. I. 861 × S. I. 863	38 „	6
XXXVI	S. I. 862 × S. I. 863	23 „	6
XL	S. I. 863 × S. I. 869	26 „	6

It will be obvious that the Buffs producing the Black F_1s fall into two groups with one or other of the genetic compositions, bbIIKK, BBiiKK. The F_2 from the 24 selections carried forward is presented in Table VIII.

TABLE VIII.

Pure for K. Segregating for B and I.

Generation	Family No.	Grain Colours.			
		Black BBIIKK	Tawny Buff bbIIKK	Korra Buff.	
				BBiiKK	bbiiKK
Parents.	Buffs of (bbIIKK) and (BBiiKK)	..	..		
F_1	S. I. Cross XXV	..	..		
	XXXIII	..	..		
	XXXVI	..	..		
	XL	..	..		
F_2	(From S. I. Cross XXV)—				
	S. I. 1274 to 1279 (BbIiKK)	321		300	
F_2	(From S. I. Cross XXXIII)—				
	S. I. 1280 to 1285 (BbIiKK)	218		203	
F_2	(From S. I. Cross XXXVI)—				
	S. I. 1286 to 1291 (BbIiKK)	423		316	
F_2	(From S. I. Cross XL)—				
	S. I. 1292 to 1297 (BbIiKK)	450		353	
	Total	1,412		1,172	
	$X^2 = 2{\cdot}7$				
	$p = 0{\cdot}1$				

The following table gives the history of a clan pure for the B factor, and segregating for both the factors K and I.

TABLE IX.

Pure for B. Segregating for K and I.

Generation	Family No.	Grain Colours			
		Black BBIIKK	Sepia BBIIkk	Korra Buff BBiiKK	Tawny Red BBiikk
Natural Cross (1925)					
F_2	S. I. 269	18		8	
F_3 *Character of Selections*					
Blacks . .	S. I. 383, 386, 389, 390, 395, 397, 406, 407 (BBIIKK) or (BBIIkk)	All		..	..
„ . .	S. I. 385, 396, 405 (BBIiKk) .	211		47	18
„ . .	S. I. 393, 394, 398, 399, 404 (BBIiKK) . .	252	..	79	..
„ . .	S. I. 384, 392 (BBIikk) .	..	160	..	53
Korra Buff .	S. I. 387, 388 (BBiiKK) .	..	..	Pure	..
„ .	S. I. 391, 400, 401, 402, 403, 408 (BBiiKk) . .	..	..	419	100
F_4 (from S. I. 405)—					
Blacks . .	S. I. 1317, 1321, 1324, 1325 .	All		..	..
„ . .	S. I. 1319, 1320, 1322, 1323 .	242	..	62	..
„ . .	S. I. 1318	..	26	..	9
Korra Buff .	S. I. 1326	..	..	Pure	..
„ .	S. I. 1327	..	..	102	17
Tawny Red .	S. I. 1328, 1329 . . .	..	..	..	Pure

In Tables IX and X the initial difficulties experienced in the separation of the Sepias from the Blacks is reflected in a general use of a consolidated total under "Blacks" as such. Later, however, with the help of the immature grain of the ear-head, this separation has been possible and tended to increasing definiteness.

It is noteworthy that the Tawny Reds, lacking the K and I factors, are rather poor in vigour and economically not so sound as others of different genetic compositions. This poverty results in a weaker survival value as is evidenced by the poor population of even the extracted pure types.

The following table presents a clan pure for the I factor and segregating for the factors B and K :—

TABLE X.

Pure for I. Segregating for B and K.

Generation	Family No.	Grain Colours			
		Black BBIIKK	Sepia BBIIkk	Tawny Buff bbIIKK	Red bbIIkk
Natural Cross (1926)					
F_2	S. I. 272	131		48	14
F_3					
Character of Selections.					
Blacks	S. I. 1039, 1041 (BbIIKk)	309		87	25
„	S. I. 1038, 1044 (BbIIKK)	321	..	111	..
„	S. I. 1037, 1042 (BbIIkk)	..	296	..	92
„	S. I. 1040, 1043, 1045	All		..	..
Tawny Buff	S. I. 1046, 1049 (bbIIKK)	..	..	Pure	..
„	S. I. 1047, 1048 (bbIIKk)	..	..	339	109
Red	S. I. 1050 (bbIIkk)	..	..	..	Pure
F_4 (from S. I. 1041)—					
Blacks	S. I. 1725, 1729, 1733, 1731	All		..	..
„	S. I. 1723, 1726, 1728	322	..	109	..
„	S. I. 1724, 1732, 1734	..	356	..	102
„	S. I. 1727, 1730	261		73	10
F_4 (from S. I. 1044)—					
Black	S. I. 1737, 1738	Pure	..	..	..
„	S. I. 1735, 1736	496	..	139	..
F_4 (from S. I. 1037)—					
Sepia	S. I. 1718, 1720	..	Pure	..	..
„	S. I. 1719, 1721	..	446	..	135
Red	S. I. 1722	..	..	..	Pure

The final set of tables present clans segregating for all the three factors B, I and K. Of these, clan S. I. 758 (Table XI) runs up to the third generation, clans S. I. 209, 524 and 555 to the fourth generation, and clan S. I. 85 up to the fifth. These have been exhaustively worked out to get all the possible theoretical segregations from a 3-factor interaction.

TABLE XI.

Segregating for B, I and K.

Generation	Family No.	Grain Colours							
		Black	Sepia	Tawny Buff	Korra B		Red	Tawny Red	
		BBIIKK	BBIIkk	bbIIKK	BBiiKK	bbiiKK	bbIIkk	BBiikk	bbiikk
Natural Cross (1927)									
F_2	S. I. 758	43		19	13		2	?	
F_3 *Character of & Selections.*									
Black	S. I. 1381 (BbIiKK)	115	..	36	34		..	..	..
,,	S. I. 1376, 1380 (BbIIKk)	319		72	..	..	12	..	..
,,	S. I. 1377, 1378 (BBIiKk)	286		..	64	..	..	15	..
,,	S. I. 1379 (BbIIkk)	..	103	..	..	..	27	..	..
,,	S. I. 1374, 1375, 1382 (BbIikk)	..	327	..	..	..	128	147	

TABLE XII.

Clan S. I. 209. Segregating for B, I and K.

Generation	Family No.	Grain Colours							
		Black	Sepia	Tawny Buff	Korra Buff		Red	Tawny Red	
		BBIIKK	BBIIkk	bbIIKK	BBiiKK	bbiiKK	bbIIkk	BBiikk	bbiikk
Natural Cross (1926)									
F_2	S. I. 209	65		15	28		4	?	
F_3									
Character of Selections.									
Blacks	S. I. 786, 788, 798 (BbIiKk)	165		59	57		21	?	
,,	S. I. 787, 793, 796 (BbIiKK)	196	..	61	75		..	..	
,,	S. I. 790, 791 (BBIiKK)	170	..	..	64	..	..	..	
,,	S. I. 792 (BbIIKk)	83		28	..	..	11	..	
,,	S. I. 789, 797 (BBIiKk)	204		..	54	..	..	14	..
,,	S. I. 794, 795 (BbIIkk)	..	262	..	..	..	90	..	..
Tawny Buff	S. I. 801 (bbIiKK)	..	..	94	..	26	..	..	..
,,	S. I. 802 (bbIiKk)	..	..	27	..	12	6	..	..
,,	S. I. 799, 803	..	..	..	..	..	..	All	
Korra Buff	S. I. 804, 805	..	..	..	All		..	..	
	S. I. 806 to 808	..	..	..	262		..	76	
Red	S. I. 809 to 812	..	..	..	..		Pure	..	

TABLE XII—*contd.*

Clan S. I. 209 (F_4 Generation). Segregating for B, I and K.

Generation	Family No.	Grain Colours							
		Black	Sepia	Tawny Buff	Korra Buff		Red	Tawny Red	
		BBIIKK	BBIIkk	bbIIKK	BBiiKK	bbiiKK	bbIIkk	BBiikk	bbiikk
F_4 (from S. I. 797).									
Character of Selections.									
Black . .	S. I. 1411, 1412, 1414, 1418.	311		..	74	..	..	14	..
,, . .	S. I. 1415, 1419 . .	74	..	..	26	..	..	..	..
,, . .	S. I. 1410, 1413, 1416, 1417.	All		..	..	..	..	..	..
Korra Buff .	S. I. 1422, 1423 . .	..	..	..	Pure	..	..	..	..
Tawny Red .	S. I. 1420, 1421 . .	..	..	..	..	..	..	Pure	..
F_4 (from S. I. 792).									
Black . .	S. I. 1405 . . .	All		..	..	..	..	..	..
,, . .	S. I. 1403 . . .	73	..	28	..	..	..	..	..
,, . .	S. I. 1402, 1404 . .	..	51	..	..	..	24	..	..
F_4 (from S. I. 795).									
Sepia . .	S. I. 1407, 1408 . .	..	Pure	..	..	..	..	..	..
,, . .	S. I. 1406 . . .	..	88	..	..	..	35	..	..
Red . .	S. I. 1409 . . .	..	..	..	..	..	Pure	..	..

TABLE XIII.

Clan S. I. 524. Segregating for B, I and K.

Generation	Family No.	Grain Colours							
		Black	Sepia	Tawny Buff	Korra Buff		Red	Tawny Red	
		BBIIKK	BBIIkk	bbIIKK	BBiiKK	bbiiKK	bbIIkk	BBiikk	bbiikk
Natural Cross (1926)									
F_2	S. I. 524	65			57		7	?	
F_3									
Character of Selections									
Black	S. I. 959, 961 (BbIiKk)	165		46	82		16	4	
,,	S. I. 960	All		..	..		..	..	
Tawny Buff	S. I. 963 (bbIiKK)	..		134	..	43	..	..	
,,	S. I. 964 (bbIIKk)	..		89	..	..	39	..	
Korra Buff	S. I. 962	..		..	50		..	27	
Red	S. I. 965 (bbIikk)	..		..	..		142	42	
F_4 (from S. I. 959).									
Black	S. I. 1600	108	..	17	..	..	..	..	..
,,	S. I. 1598, 1602	241	..	..	66	..	..	..	..
,,	S. I. 1597, 1599	209		46	..	..	20	..	..
,,	S. I. 1601	121		..	26	..	..	14	..
,,	S. I. 1607	..	84	..	..	..	27	..	..
,,	S. I. 1603, 1604, 1608	..	411	..	..	..	..	168	..
,,	S. I. 1605, 1606	..	169	..	..	..	63	84	

TABLE XIV.

Clan S. I. 555. Segregating for B, I and K.

Generation	Family No.	Grain colours							
		Black	Sepia	Tawny Buff	Korra	Buff	Red	Tawny Red	
		BBIIKK	BBIIkk	bbIIKK	BBiiKK	bbiiKK	bbIIkk	BBiikk	bbiikk
Natural Cross (1926)									
F_2	S. I. 555	31		32		4		?	
F_3									
Character of Selections.									
Black	S. I. 968	All		..	..	..	..	..	..
"	S. I. 970, 972	228		61	71		11	3	
"	S. I. 971	47	..	12	..	..	..	..	..
"	S. I. 967	35	..	..	17	..	..	..	..
"	S. I. 969	..	79	..	..	..	22	39	
Red	S. I. 973, 974, 975	..	..	..	..	..	245	78	
F_4 (FROM S. I. 972).									
Black	S. I. 1622, 1630	All		..	..	..	..	..	..
"	S. I. 1631, 1635 (BbII KK).	40	..	15	..	..	..	..	..
"	S. I. 1619 (BBIiKK)	201	..	..	74	..	..	..	..
"	S. I. 1620, 1624, 1626, 1634 (BbIiKK).	292	..	47	100		..	..	..
"	S. I. 1627, 1628, 1629 (BbIiKk)	191		34	77		21	13	
"	S. I. 1625 (BbIIkk)	..	153	..	..	..	48	..	..
"	S. I. 1621, 1623, 1632 (BbIikk).	..	223	..	..	..	84	98	
F_4 (FROM S. I. 969).									
Sepia	S. I. 1609 to 1612, 1618.	..	450	..	..	..	172	185	
"	S. I. 1615, 1617	..	274	..	..	..	108	..	..
"	S. I. 1613, 1614, 1616 (BBIikk).	..	269	..	..	..	..	101	..

TABLE XV.

Clan S. I. 85 (F_2 and F_3). Segregating for B, I and K.

Generation	Family No.	Grain colours									
		Black		Sepia	Tawny Buff	Korra Buff		Red	Tawny Red	
		BBIIKK		BBIIkk	bbIIKK	BBiiKK	bbiiKK	bbIIkk	BBiikk	bbiikk
Natural Cross (1922).										
F_2 . . .	S. I. 85 . . .	67			39			2	?	
F_3 *Character of selections.*										
Black . .	S. I. 205 . . .	211		..	83	..	..	..	..	..
,, . .	S. I. 204 . . .	179		..	62	65		..	..	..
,, . .	S. I. 206 . . .	219			..	52	..	..	15	..
,, . .	S. I. 203 . . .	..		177	..	..	..	61	79	
Non-black .	S. I. 208 . . .	..		..	..	All		..	..	..
,, . .	S. I. 207 . . .	..		..	..	..	..	..	All	

TABLE XVI.

Clan S. I. 85 (F_4 and F_5).

Family S. I. 205.

Pure for I and K. Segregating for B.

Generation	Family No.	Grain colours	
		Black	Tawny Buff
		BBIIKK	bbIIKK
F_4 (FROM S. I. 205).			
Character of selections.			
Black	S. I. 355, 356, 357 (BbIIKK) . . .	231	81
Tawny Buff . . .	S. I. 358, 359, 360 (bbIIKK) . . .	..	Pure
F_5 (FROM S. I. 357).			
Black	S. I. 1315 (BBIIKK)	Pure	..
,, ...	S. I. 1313, 1314, 1316 (BbIIKK) . .	293	96

TABLE XVII.

Clan S. I. 85 (F_4 and F_5)—contd.

Family S. I. 204.

Pure for K. Segregating for B and I.

Generation	Family No.	Grain colours			
		Black	Tawny Buff	Korra Buff	
		BBIIKK	bbIIKK	BBiiKK	bbiiKK
F_4 (FROM S. I. 204).					
Character of selections.					
Black . . .	S. I. 766, 769 (BbIiKK) .	123	27	31	
„ . . .	S I. 767, 768 (BBIiKK) .	197	..	71	..
Tawny Buff . .	S. I. 771 (bbIIKK) . .	..	Pure	..	..
„ . .	S. I. 770, 772 (bbIiKK) .	..	177	..	64
Korra Buff . .	S. I. 773, 774, 775 (BBiiKK) or (bbiiKK).	..	..	All	
F_5 (FROM S. I. 769).					
Black . . .	S. I. 1100 (BBIIKK) . .	Pure	..	..	..
„ . . .	S. I. 1102 to 1104 . .	489	188	..	..
„ . . .	S. I. 1099 . . .	179	..	56	..
„ . . .	S. I. 1101	135	46	54	
F_5 (FROM S. I. 767).					
Black . . .	S. I. 1383	Pure	..	..	..
„ . . .	S. I. 1384 to 1386 . .	393	..	143	..
Korra Buff . .	S. I. 1387 (BBiiKK) . .	..	..	Pure	..
F_5 (FROM S. I. 770).					
Tawny Buff . .	S. I. 1389	..	Pure	..	..
„ . .	S. I. 1388, 1390 . . .	..	206	..	56
Korra Buff . .	S. I. 1391 (bbiiKK) . .	..	..	..	Pure

TABLE XVIII.

Clan S. I. 85 (F_4 and F_5)—contd.

Family S. I. 206.

Pure for B. Segregating for I and K.

Generation	Family No.	Grain colours			
		Black	Sepia	Korra Buff	Tawny Red
		BBIIKK	BBIIkk	BBiiKK	BBiikk
F_4 (FROM S. I. 206).					
Character of Selections.					
Black . . .	S. I. 779	All		..	..
„ . . .	S. I. 776, 778, 780 (BBIiKK)	298	..	86	..
„ . . .	S. I. 777 (BBIikk) . .	..	78	..	32
Korra Buff . .	S. I. 782 (BBiiKK) . .	..	..	Pure	..
„ . .	S. I. 781 (BBiiKk) . .	..	..	68	18
Tawny Red .	S. I. 784, 785 (BBiikk) . .	..	..	..	Pure
F_5 (FROM S. I. 777).					
Sepia . . .	S. I. 1392, 1393 (BBIIkk) .	..	Pure	..	..
„ . . .	S. I. 1394, 1395 . . .	..	162	..	51
Tawny Red . .	S. I. 1396, 1397 . . .	..	..	..	Pure
F_5 (FROM S. I. 781).					
Korra Buff . .	S. I. 1398 (BBiiKK) . .	..	..	Pure	..
„ . .	S. I. 1399, 1400 . . .	..	..	75	18
Tawny Red . .	S. I. 1401	..	..	..	Pure

TABLE XIX.

Clan S. I. 85 (F_4 and F_5)—concld.

Family S. I. 203.

Pure for absence of K. Segregating for B and I.

Generation	Family No.	Grain colours			
		Sepia	Red	Tawny Red	
		BBIIkk	bbIIkk	BBiikk	bbiikk
F_4 (FROM S. I. 203).					
Character of Selections.					
Sepia . . .	S. I. 328, 340 (BbIIkk) .	79	19	..	..
,, . . .	S. I. 323, 324, 339, 343, 344 (BBIikk).	129	..	45	..
,, . . .	S. I. 325 to 327, 329 to 331, 341, 342, 345 to 347 (BbIikk).	384	135	131	
Red . . .	S. I. 337, 353 (bbIIkk).	..	Pure	..	..
,, . . .	S. I. 336, 338, 352, 354 (bbIikk).	..	157	..	40
Tawny Red . .	S. I. 332 to 335, 348 to 350 .	..	..	All	
F_5 (FROM S. I. 323).					
Sepia . . .	S. I. 1302, 1303 (BBIIkk) .	Pure	..	..	..
,, . . .	S. I. 1301, 1304 (BBIikk) .	156	..	53	..
Tawny Red . .	S. I. 1305 (BBiikk) . .	..	..	Pure	..
F_5 (FROM S. I. 352).					
Red . . .	S. I. 1307 to 1310 (bbIikk) .	..	125	..	46
Tawny Red . .	S. I. 1311, 1312 (bbiikk) .	..	..	..	Pure

With increased experience and in the light of the above segregates it has been possible to separate out similar families even in the F_2 into five groups, and the following table presents two such families from the latest crop.

TABLE XX.

Segregating for B, I and K.

Generation	Family No.	Grain colours									
		Black		Sepia	Tawny Buff	Korra Buff		Red	Tawny Red	
		BBIIKK	BBIIkk		bbIIKK	BBiiKK	bbiiKK	bbIIkk	BBiikk	bbiikk
Natural Cross (1929). F_2 . . .	S. I. 1299 . . .	127			29	27		7	6	
Natural Cross (1929). . . .	S. I. 1856 . . .	144			39	44		14	12	

In view of the exhaustively worked out clans S. I. 85, 555, etc., these two families have not been carried forward to further generations, but the fact is obvious that the segregations are of the 36 : 9 : 12 : 3 : 4 type. The paucity of the Tawny Reds has already been explained elsewhere.

This genetic analysis has made it possible to separate out and give a definite individuality to the six grain colours of this Millet, in spite of the difficulties experienced in the separation within Buffs, Tawnys and Blacks. It is no wonder that in the absence of this equipment earlier work has tended to confine itself to the three patent colours Black, Buff and Red only.

In verification of this three-factor hypothesis, artificial crosses Nos. LXVI, LXVII and LXVIII were made between a Red (bbIIkk) S. I. 1272 and a Korra Buff (BBiiKK) S. I. 1005 and true to expectations Black-grained hybrids (BbIiKk) were obtained. Nineteen of these when sown segregated as follows :—

Season 1931 Summer	Black Sepia 36	Tawny Buff 9	Korra Buff 12	Red 3	Tawny Red 4
FAMILIES.					
S. I. 1886-1904 . . .	2097	498	742	170	259
Theoretical expectation .	2117	531	708	177	235

SUMMARY.

Six grain colours have been noted in *Setaria italica*. These fall into two groups (*a*) Black, Tawny Buff and Korra Buff, and (*b*) Sepia, Red and Tawny Red. A factor K (after Korra, the Telugu name for this Millet) is present in group (*a*) and absent in group (*b*). In each of these groups the basic colours Tawny Red and Korra Buff, with the addition of a factor I, turn into Red and Tawny Buff. This Red and Tawny Buff with the addition of another factor B turn into Sepia and Black respectively. Factor B has an individuality, but its presence is not visible except in association with I.

The behaviours of over five hundred families are presented in support of the above hypothesis. Three sets of artificial crosses furnish confirmatory evidence.

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SOME BIRD ENEMIES OF THE DESERT LOCUST (*SCHISTOCERCA GREGARIA*, FORSK.) IN THE AMBALA DISTRICT (PUNJAB).

BY

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During the spring of 1930 an intensive infestation of the Desert Locust occurred in the Punjab and this provided an opportunity of studying the birds that preyed on this insect. The observations recorded below were made mainly in two tehsils of the Ambala district—Naraingarh and Kharar—which are bounded on the North-East by the Siwalik range and are partly hilly and partly sub-montane. The river Jumna separates this area from the adjoining Saharanpur district of the United Provinces.

The fliers were reported from about the beginning of February, and egg-laying started about the middle of this month and continued till the end of April. The hoppers, as well as the fliers, were present all through the months of March, April and May. The observations on the locust-eating birds were started from the 21st February and were continued till the 3rd May 1930. Wherever possible, the birds found eating eggs, hoppers and fliers, were shot and their stomach contents examined. In a few cases where the birds could not be shot it was definitely ascertained by actual observations that such birds were feeding on locusts.

In all 35 species of wild birds belonging to 18 families were observed eating locusts. The following by virtue of their numbers, must be regarded as the major enemies of this pest :—

The Common Indian House Crow, the Rosy Pastor, the Common Myna, and the Northern Grey Partridge.

The importance of a particular species depends on the number of the locusts destroyed ; and this depends on the size of the individuals and their abundance ; the number being evidently the more important factor.

A number of domesticated birds such as poultry (fowls), Guinea fowls and swans also ate locusts. Guinea fowls are kept in large numbers in Kharar tehsil. Flocks of these birds were led to bushes where locust hoppers had gathered and were found to enter the bushes and eat these hoppers voraciously.

Another bird of importance which although not shot in Ambala, the White Stork (*Ciconia ciconia*) locally known as *Laha Sarang*, was noticed eating locust adults at Bir Badri (tehsil Jhajjar, district Rohtak) and at Hafizabad (Gujranwala). Flocks of these birds appeared and were seen arrayed in lines eating locusts. This bird is restricted to swampy places.

Although the combined efforts of all these birds may not effectively check an onslaught of the pest, yet they render invaluable service to us and play a very important part in exterminating thin swarms, which cannot be dealt with economically through human agency, and in destroying those numerous individuals which escape even the most vigorous onslaught of man. It is, therefore, important that a further study of the fauna of all the localities infested by locusts be undertaken, and such of the birds as appear to be friendly given special protection. Mr. Whistler studied the avian fauna of the Ambala district and published his results as 'Notes on the birds of Ambala district (Punjab)' in the Journal of the Bombay Natural History Society, Vols. XXV and XXVI, 1917 and 1920. More extensive studies on similar lines are very desirable.

It is often stated that crows and starlings are enemies of locusts and kill them, so to say, for sport, thus destroying far more than they actually require for food. Both these birds may be seen cutting large numbers of locusts into two. It seems that ordinarily these birds do not get sufficient practice in catching fast flying insects, in their effort to secure their prey they snap at it with vigour and rapidity and thus cut it into two, and the parts of the insect, thus cut, drop down. When these birds have secured their prey they perch on a tree, close by, and start eating their victim.

The following is the list of the locust eating birds :—

Note :—The abbreviations used in the statement :—

Abundance of Birds.
R—Rare.
C—Common.
CC—More common.
VC—Very common.
VVC—Abundant-in swarms.

Status as beneficial birds.
m —of minor importance.
M— of major importance.
VM—very important.

Egg, hopper, adult—Various stages of *Schistocerca gregaria*
\+ —Found in the stomach, or actually observed feeding.
— —Not found in the stomach.

Serial No.	Name of the bird. 1. English. 2. Vernacular. 3. Scientific (after Fauna of British India). FAMILY.	Abundance/Status.	Egg.	Hopper.	Adult.	Other insects.	Grains, etc.	Stomach contents. Locality and date.
1	The Indian Jungle-Crow. (*Bara Kawa*). *Corvus coronoides levail lanti.* CORVIDÆ.	C C / M	—	+	+	+	+	1. Remains of adult locusts; beetle; loaf and vegetable matter: *Panjokhra* (*Teh. Ambala*) : 15th March 1930. 2. Large number locust hoppers; wheat grains; vegetable matter : *Kharar* : 13th April 1930. 3. Locust hoppers; parts of beetle; wheat and maize grains : *Kharar :* 13th April 1930.
2	The Common Indian House-Crow. (*Kawa*). *Corvus splendens splendens.* CORVIDÆ.	V C / V M	—	+	+	+	+	1. Locust adults; wheat and maize grains; vegetable matter: *Shehzadpur* (*Teh. Naraingarh*) : 21st February 1930. 2. Mainly locust adults: *Shehzadpur :* 27th February 1930. 3-4. Mainly locust adults: *Shehzadpur :* 18th March 1930. 5. Mainly locust hoppers: *Shehzadpur :* 22nd March 1930. 6. Large number of cutworms; beetle; few locust hoppers; maize: *Shehzadpur :* 26th March 1930. 7-8. Locust hoppers (20); locust parts; maize and wheat grains : *Kharar :* 5th April 1930. 9. Locust hoppers; wheat and lentil grains : *Kharar :* 8th April 1930.

Serial No.	Name of the bird. 1. English. 2. Vernacular. 3. Scientific (after Fauna of British India). FAMILY.	Abundance/Status.	Egg.	Hopper.	Adult.	Other insects.	Grains, etc.	Stomach contents. Locality and date.
								10. Locust hoppers; ants and beetles; wheat and gram grain: *Kharar:* 10th April 1930.
								11. Locust hoppers and insect parts; loaf; wheat and maize grains: *Kharar:* 29th April 1930.
								12. Locust hoppers and insects; loaf; wheat and maize grains: *Kharar:* 29th April 1930.
								13. Adult locusts mainly: *Kharar:* 4th May 1930.
3	The Indian Tree-Pie (*Mutri or Mahalat*). *Dendrocita rufa rufa.* CORVIDÆ.	C / M	—	+	—	+	—	1. Locust hoppers; caterpillars (14); insect parts: *Kharar:* 24th April 1930.
								2. Mainly locust hoppers: *Kharar:* 26th April 1930.
4	The Bengal Jungle Babbler. (*Sori*). *Turdoides terricolor terricolor.* TIMALIIDÆ.	C / m	+	+	—	+	+	1. Locust hoppers 1st stage; vegetable matter: *Shehzadpur*: 18th March 1930.
								2. Locust hoppers; ants; insect parts; weed seeds: *Shehzadpur*: 26th March 1930.
								(This bird was also observed taking locust eggs but could not be killed.)
5	The Punjab Red-Vented Bulbul. (*Bulbul*). *Molpastes haemorrhous intermedius.* PYCNONOTIDÆ.	C / m	—	+	+	—	+	1. Locust adult and parts: *Shehzadpur*: 21st February 1930.
								2. Insect parts; Ficus fruit: *Kharar*: 12th April 1930.
								3. Locust hoppers and parts; Ficus fruit: *Kharar*: 14th April 1930.

Serial No.	Name of the bird. 1. English. 2. Vernacular. 3. Scientific (after Fauna of British India). FAMILY.	Abundance/Status.	Egg.	Hopper.	Adult.	Other insect.	Grains, etc.	Stomach contents. Locality and date.
6	The Brown-backed Indian Robin. (*Dama*). *Saxicoloides fulicata cambaiensis*. TURDIÆ.	C / m	—	+	—	+	—	1. Locust hoppers: *Shehzadpur:* 24th March 1930. 2. Locust hoppers; beetle parts; caterpillars; insect parts: *Shehzadpur:* 27th March 1930.
7	The Indian Magpie-Robin (*Dayal*). *Copsychus saularis saularis*. TURDIDÆ.	C / m	—	+	+	+	—	1. Adult locust; ants; insect parts: *Shehzadpur:* 21st February 1930. 2. Locust adult; insect parts: *Shehzadpur:* 28th February 1930. 3. Mostly locust hoppers; insect parts: *Kharar:* 15th April 1930.
8	Robin . . . . TURDIDÆ.	C / m	—	+	—	+	—	1. Locust hoppers; caterpillars; beetles: *Shehzadpur:* 29th March 1930.
9	Fly catcher sp. . . MUSCICAPIDÆ.	C / m	—	+	—	—	—	This bird was not killed but was seen eating locust hoppers: *Shehzadpur:* 29th March 1930.
10	The Indian Grey Shrike . (*Lahtora*). *Lanius excubitor lahtora* . LANIIDÆ.	C / M	—	+	+	+	—	1. Locust adult; beetle elytron: *Shehzadpur:* 19th March 1930. 2. Locust hoppers; beetle elytron; insect parts: *Shehzadpur:* 22nd March 1930.
11	The Rufous-backed Shrike. (*Chhota lahtora*). *Lanius schach erythronotus*. LANIIDÆ.	C / m	—	+	+	+	—	1. Locust hoppers; ants; insect parts: *Shehzadpur:* 22nd March 1930.

Serial No.	Name of the bird. 1. English. 2. Vernacular. 3. Scientific (after Fauna of British India). FAMILY.	Abundance/Status.	Egg.	Hoppers.	Adult.	Other insects.	Grains, etc.	Stomach contents. Locality and date.
12	The Black Drongo or King Crow. (*Chepu or Bhuchanga*). *Dicrurus macrocercus macrocercus.* DICRURIDÆ.	C C / M	—	+	+	+	—	1. Locust adult; insect parts; *Shehzadpur*: 28th February 1930. 2. Large number of locust hoppers; beetle head and parts: *Shehzadpur*: 27th March 1930. 3. Locust hoppers (11); beetles (2): *Kharar*: 10th April 1930. 4. Locust hoppers; beetle head; moth; insect parts: *Kharar*: 23rd April 1930.
13	The Rosy Pastor or Rose-coloured Starling. (*Gulabi-Tiliar*). *Pastor roseus.* STURNIDÆ.	V V C / V M	—	+	+	—	+	1-4. Mainly locust adults: *Panjokhra*: (*Tehsil Ambala*): 15th March 1930. 5-7. Mainly locust hoppers: *Kharar*: 13th April 1930. 8-11. Mostly locust hoppers: Ficus fruit *Kharar*: 13th April 1930.
14	The Himalayan starling. (*Tiliar*). *Sturnus vulgaris humii*. STURNIDÆ.	V C / M	+	+	+	+	+	1-2. Locust hoppers; caterpillars; ants; *Shehzadpur*: 21st March 1930. 3. Large number of cutworms and their pupae; insect parts: *Shehzadpur*: 22nd March 1930. 4-5. Large number of cutworms; lacewing-fly pupae (3); ants; insect parts: *Shehzadpur*: 22nd March 1930. 6. Large number of cutworms; one beetle: *Shehzadpur*: 22nd March 1930. 7-9. Large number of cutworms; lacewing-fly pupae: *Shehzadpur*: 22nd March 1930.

Serial No.	Name of the bird. 1. English. 2. Veruacular. 3. Scientific (after Fauna of British India). FAMILY.	Abundance/Status.	Egg.	Hopper.	Adult.	Other insects.	Grains, etc.	Stomach contents. Locality and date.
								10. Cutworms; other caterpillars; beetle; few lacewing-fly pupae :*Shehzadpur :* 1st April 1930.
								11. Locust hoppers; cutworms; other caterpillars; b eetle; few lacewing- fly pupae : *Shehzadpur :* 1st April 1930.
								12. Cutworms; ants; lacewing-fly pupae: *Shehzadpur :* 1st April 1930.
15	The Black-headed Myna. (*Bahmni myna or Pawii*). *Temenuchus pagodarum.* STURNIDÆ.	C C / M	—	+	+	+	+	1. Locust hoppers (11): locust hopper heads (5); insect parts: *Kharar :* 14th April 1930.
								2. Locust hoppers (26); Ficus fruits: *Kharar :* 14th April 1930.
								3-4. Mainly locust hoppers: *Kharar :* 25th April 1930.
								5-6. Mainly locust hoppers: *Kharar :* 3rd May 1930.
16	The Common Myna . (*Sharak or lalri*). *Acridotheres tristis tristis.* STURNIDÆ.	V C / M	+	+	+	+	+	1. Mainly locust adults: *Shehzadpur :* 21st February 1930.
								2. Eggs-shells locust; insect parts; wheat and lentil grains: *Shehzadpur :* 1st March 1930.
								3-4. Locust hoppers mainly: *Shehzadpur :* 21st March 1930.
								5. Large number of locust hoppers; cutworms; weed seeds: *Shehzadpur :* 27th March 1930.
								6. Ficus fruits; wheat and lentil grains: *Shehzadpur :* 29th March 1930.

Serial No.	Name of the bird. 1. English. 2. Vernacular. 3. Scientific (after Fauna of British India). FAMILY.	Abundance/Status.	Egg.	Hopper.	Adult.	Other insects.	Grains, etc.	Stomach contents. Locality and date.
								7. Beetles (4); Ficus fruits: *Shehzadpur:* 29th March 1930.
								8-9. Locust hoppers; ants and wheat grains: *Kharar:* 6th April 1930.
								10. Locust hoppers and parts; ants; beetle elytron; wheat grains: *Kharar:* 10th April 1930.
								11-15. Mainly locust hoppers; *Kharar:* 23rd, 26th April 1930 and 2nd, 3rd May 1930.
17	The Bank Myna . . (*Ganga Myna.*) *Acridotheres ginginianus.* STURNIDÆ.	C / m	—	+	+	+	+	1. Mainly locust adults: *Shehzadpur:* 19th March 1930.
								2. Locust hoppers; insect parts; Ficus fruits: *Shehzadpur:* 23rd March 1930.
								3. Mostly Ficus fruits; caterpillar; *Shehzadpur:* 29th March 1930.
18	The Indian House-Sparrow. (*Chiri*). *Passer domesticus indicus.* FRINGILLIDÆ.	V V C / M	—	+	—	+	+	1-2. Locust hoppers; wheat grains; vegetable matter: *Kharar:* 21st April 1930.
								3. Cutworms; locust hoppers; wheat grains: *Shehzadpur:* 24th March 1930.
								4. Locust hoppers; cutworms; *Shehzadpur:* 24th March 1930.
								5. Locust hoppers; caterpillars; wheat grains: *Kharar:* 2nd May 1930.
19	The Masked Wagtail . (*Dhobin.*) *Motacilla alba personata.* MOTACILLIDÆ.	C / m	+	+	—	+	—	1-2. Locust eggs; ants; insect parts: *Shehzadpur:* 1st and 25th March 1930.

Serial No.	Name of the bird. 1. English. 2. Vernacular. 3. Scientific (after Fauna of British India). FAMILY.	Abundance/Status.	Egg.	Hopper.	Adult.	Other insect.	Grains, etc.	Stomach contents. Locality and date.
20	The Indian Pipit . . *Anthus richardi rufulus.* MOTACILLIDÆ.	C / m	—	+	—	+	—	1. Locust hoppers; and parts; caterpillars: *Shehzadpur:* 26th March 1930.
21	Franklin's Crested Lark. (*Chandool*). *Galerida cristata Chendoola* ALAUDIDÆ.	C / m	—	+	—	+	—	This bird was not killed but was seen taking locust hoppers: *Kharar:* 13th April 1930.
22	The Common Hawk-Cuckoo. (*Popiya.*) *Hierococcyx varius.* CUCULIDÆ.	C C / M	—	+	+	+	—	1 Locust hoppers and parts; caterpillars; insect remains: *Kharar:* 24th April 1930. 2. Observed taking adult locusts.
23	The Punjab Sirkeer . (*Jangli tota*). *Taccocua leschenaulti sirkee.* CUCULIDÆ.	R / m	—	+	—	—	—	1. Mainly locust hoppers: *Kharar*: 24th April 1930.
24	The Indian Roller . . (*Nilkanth*). *Coracias benghalensis benghalensis.* CORACIIDÆ.	C C / M	—	+	+	+	—	1. Mostly locust adults; dung beetle: *Shehzadpur:* 27th February 1930. 2. Mostly locust hoppers; caterpillars: *Kharar:* 25th April 1930.
25	The Indian Hoopoe . (*Hudhud*). *Upapa epop orientalis.* UPUPIDÆ.	C C / M	—	+	—	+	—	1. Locust hoppers (9); caterpillars; insect parts: *Kharar:* 14th April 1930. 2. Locust hoppers; caterpillars; insect parts: *Kharar:* 1st May 1930.

Serial No.	Name of the bird. 1. English. 2. Vernacular. 3. Scientific (after Fauna of British India). FAMILY.	Abundance/Status.	Egg.	Hopper.	Adult.	Other insects.	Grains, etc.	Stomach contents. Locality and date.
26	The Northern spotted owlet. (*Chugal*). *Athene brama indica.* ASIONIDÆ.	C C / M	—	+	+	+	—	1. Adult locust heads and parts; beetle and insect parts: *Shehzadpur:* 21st February 1930. 2. Rhinocerous beetle; mostly; beetle elytron; insect parts: *Kharar:* 9th April 1931. 3. Locust hoppers; Rhinocerous beetle: *Kharar:* 9th April 1931. 4. Locust hoppers; beetle elytron; insect parts: *Kharar:* 26th April 1930. 5. Locust hoppers; Rhinocerous beetle; insect parts: *Kharar:* 28th April 1930.
27	The Himalayan Griffon. *Gyps himalayensis.* AEGYPIIDÆ.	C / m	—	+	+	—	—	This bird could not be killed but it was observed taking locust adults and hoppers: *Shehzadpur:* 19th March 1930.
28	The Laggar Falcon (*Laggar*). *Falco Jugger.* FALCONIDÆ.	C / m	—	+	—	—	—	This bird could not be killed but it was seen taking locust hoppers: *Shehzadpur:* 19th March 1930.
29	The Red-Headed Merlin (*Turmati*). *Falco chiquera chiquera.* FALCONIDÆ.	C / m	—	+	+	—	—	This bird could not be killed but it was observed taking locust adults and hoppers: *Shehzadpur:* 19th March 1930.
30	The Common Pariah kite (*Chil*). *Milvus migrans govinda.* FALCONIDÆ.	C C / M	—	+	+	+	—	1. Adult locust heads and parts; animal rubbish: *Panjokhra* (*Teh. Ambala*): 15th March 1930. 2. Locust hoppers; animal rubbish: *Kharar:* 15th April 1930.

Serial No.	Name of the bird. 1. English. 2. Vernacular. 3. Scientific (after Fauna of British India). FAMILY.	Abundance /Status.	Egg.	Hopper.	Adult.	Other insects.	Grains, etc.	Stomach contents. Locality and date.
31	The Indian Shikra. (*Shikra*). *Astur badius dussumieri.* FALCONIDÆ.	C / M	—	+	+	—	—	1. Mainly locust hoppers : 2. Observed taking locust adults : *Kharar :* 28th April 1930.
32	The Northern Besra Sparrow-Hawk. (*Shikra or Chirimar.*) *Accipiter virgatus affinis.* FALCONIDÆ.	C / M	—	+	+	—	—	1. Mainly locust adults : *Shehzadpur :* 19th March 1930. 2. Mainly locust hoppers : *Kharar :* 28th April 1930.
33	The Common Peafowl (*Mor*). *Pavo cristatus.* PHASIANIDÆ.	C C / M	—	+	—	—	—	This bird being sacred was not allowed to be killed but it was observed taking locust hoppers voraciously : *Kharar :* 10th April 1930.
34	The Northern Grey Partridge. (*Titar*). *Francolinus pondicerianus interpositus.* PHASIANIDÆ.	V C / V M	—	+	—	+	+	1. Insect parts ; weedseeds : *Shehzadpur :* 27th March 1930. 2-3. Locust hoppers ; white-ant workers ; pebbles and sand particles : *Shehzadpur :* 2nd April 1930. The birds were seen eating burnt or roasted locust hoppers from bushes : *Shehzadpur : Kharar :* March-April 1930.
35	The White Stork (*Laha sarang*). *Ciconia ciconia ciconia.* CICONIIDÆ.	C C / M	—	—	+	—	—	These birds have been noticed eating locust adults at *Bir Badri* (*Tehsil Jhaggar, district Rohtak*) and *Hafizabad* (*Gujranwala*) ; flocks of these birds appeared and were seen arrayed in lines eating locust adults.

SELECTED ARTICLE

MAGNESIUM—A POSSIBLE KEY TO THE PHOSPHORUS PROBLEM IN CERTAIN SEMI-ARID SOILS.

BY

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(Reprinted from the *Journal of the American Society of Agronomy*, Vol. 23, No. 6, June 1931.)

In recent years, it has been found that some soils of North Dakota respond favorably to phosphate fertilizers while others do not, even though crop yields be low and the content of readily available phosphorus be no more, or even less, than the responsive soils. Recent greenhouse trials with barley on a Fargo clay soil which has grown wheat continuously for 40 years, with nothing returned, have indicated a large response to magnesium oxide. The plants receiving magnesium oxide headed two weeks earlier, had more tillers, larger and stronger straw, and much larger heads of grain than other plants. Lime and other materials containing nitrogen, potassium, and phosphorus gave only small increases in comparison. Although this soil has been cropped to wheat continuously for 40 years, it is not infertile as indicated by the fact that for the past 14 years, yields have averaged about 16 bushels per acre and the present supply of readily available phosphorus is high. A further experiment with a similar Fargo clay which has been cropped to a rotation with residues returned shows a like response to magnesium oxide.

It is well-known that magnesium is an essential element and that one of its functions is in connection with phosphorus nutrition, probably as a phosphorus carrier. It may not be necessary that phosphorus enter the root as magnesium phosphate, but its movement and especially its final delivery at the point of utilization within the plant are more effective and rapid if in that form. During the ripening period phosphate is deposited in the seed as magnesium phosphate so that the young plant will have phosphate in a form immediately usable. In soils very deficient in soluble magnesium compounds, plants may actually suffer from a lack of phosphates in proper form. Magnesium hydroxide is so very insoluble that it is not to be expected that plants will be able to obtain sufficient quantities of this

element by simple hydrolysis of the carbonate. Calcium carbonate would tend, therefore, to suppress the availability of magnesium, while calcium sulfate, by double decomposition, would have the effect of rendering the magnesium more available in the form of the very soluble magnesium sulfate. This is borne out in the results obtained with barley, as calcium sulfate gave the greatest increases excepting the magnesium oxide.

These facts may be a factor in explaining the present low yields of flax in much of the north-west. Plants bearing oleaginous seeds are especially in need of magnesium phosphate for seed production. Applications of ordinary fertilizers on flax have not been successful up to now.

Many calcareous soils of the semi-arid regions that have what appears to be a high content of readily available phosphorus respond to heavy applications of phosphate fertilizers. It is quite possible that in some of these cases magnesium is limiting, and improved phosphorus nutrition is brought about by the addition of extremely large amounts of readily available phosphorus, and also by the calcium sulfate introduced in superphosphate. It is also possible that some of the crop increases obtained by sulfur fertilization can be attributed to the influence of these materials on the solubility of magnesium.

These facts may account for the apparent, frequent failure of laboratory methods to diagnose properly the phosphorus needs of semi-arid regions. In the absence of adequate soluble magnesium compounds, proper phosphate nutrition cannot be realized even though a considerable amount of readily available phosphorus is present in the soil.

The writer has further studies of this magnesium-phosphorus relationship under way with the view of determining the amounts and kinds of materials needed for a proper balance with various crop plants.

ABSTRACTS

[We are indebted to the Imperial Bureau of Plant Genetics, Herbage Plants, Aberystwyth (Wales), for the following abstracts of current publications.]

Titanium in some New Zealand soils and pastures. ASKEW, H. O. *New Zealand Journal of Science and Technology*, Vol. 12, No. 3, pages 173—179. Wellington, 1930.

Titanium was once considered to be rare, but is now tenth on the list of elements in order of abundance. Its presence in nearly all vegetable and mineral matter, in amounts varying from traces to a few hundredths of 1 per cent., is now established. In plants, it is found in largest amounts in the physiologically active portions. Although present only in traces, it is probably necessary for life processes. The small amount (1 mg. to 8·5 mg. as TiO_2, per 100 grm. of dry matter) found in pastures shows that titanium compounds are not present in sufficient quantity to detrimentally affect the assimilation of phosphate in the animal body by precipitation of an insoluble phosphate. Iron and titanium content would appear to be correlated, but not titanium and manganese.

Linkage in the tetraploid *Primula sinensis*. WINTON, D. de and HALDANE, J.B.S. *Journal of Genetics*, Vol. 24, No. 1, pages 121—144. Cambridge, 1931.

1. An account is given of six types of linkage observed between three pairs of factors in the tetraploid *Primula sinensis*, and of a seventh theoretically possible type.

2. The intensity of linkage is nearly, but not quite, the same in the tetraploid as in the diploid. It is the same on the two sides in the tetraploid.

3. As regards the factors considered, there is no evidence of crossing-over involving more than two chromosomes at a time or of two chromosomes going to the same pole after crossing-over.

4. The six readily available gametic series contain only one adjustable constant p, and since the experimental results in other cases agree reasonably well with prediction when p has been calculated from the results of single coupling, this affords substantial support of the chromosome theory of inheritance.

Meiosis in diploid and tetraploid *Primula sinensis*. DARLINGTON, C. D. *Journal of Genetics*, Vol. 24, No. 1, pages 65—96. Cambridge, 1931.

A comprehensive study is made of mitosis and meiosis in the diploid and tetraploid *Primula sinensis* (n=12). Such questions as chromosome association by chiasmata, the number of ring bivalents in the diploid and of quadrivalents in the tetraploid segregation as applied to tetraploid and changes in the crossing-over distribution are discussed in detail.

The carbohydrate metabolism of *Stipa pulchra*. SAMPSON ARTHUR, W. AND MCCARTY, E. C. *Hilgardia*, Vol. 5, No. 4, pages 61—100. Berkeley, California, 1930.

1. The growth cycle of *Stipa Pulchra* is an orderly process characterized by periodicity, in that intervals of rapid growth alternate with intervals of depression in the growth rate. The time of growth inception of the herbage on the range studied followed closely the early autumn rains. The rate of growth during the winter is controlled by atmospheric temperatures, whereas that of the spring and early summer is in part related to internal factors, among which the food level and the growth habits of the plant appear paramount. Cessation of growth in the summer is determined by the maturity of the herbage, and may be appreciably hastened by low soil humidity.

2. Active root growth occurred in the autumn and winter when herbage growth had practically ceased.

3. The advent of flowers and seed coincided with depression in the growth rate.

4. An inverse correlation existed between the annual march of the carbohydrate foods and the growth rate. Accumulation of foods, therefore, is related to low or to declining velocity, and is most active near the close of the annual growth cycle.

5. Removal of the herbage at any time prior to the maturity of the plant was followed by more or less vigorous regeneration growth.

6. Practically complete accumulation of carbohydrate foods occurred where from 43 to 50 per cent. of the total annual herbage yield was produced prior to the peak in the growth rate. A deficiency in the accumulated food supply at the close of the annual cycle would apparently result in decreased growth during the subsequent year.

7. Grazing or clipping once or twice early in the growth cycle influenced little, if at all, the total herbage yield of *Stipa pulchra*. This treatment did not prevent the accumulation of maximum amounts of carbohydrate foods in the late part of the annual growth period.

8. Grazing or removal of the herbage between the time of flower stalk production and seed maturity prevents the accumulation of maximum amounts of carbohydrate foods and tends to prolong the vegetative growth of the plant.

9. Growth should proceed with a minimum of disturbance by grazing or other forms of harvesting during the intervals of rapid growth. Maximum utilization should follow cessation of growth and the maturity of herbage.

10. The herbage of *Stipa pulchra* on the range studied retains its succulence for a period of nine or ten months.

Cytological studies of five interspecific hybrids of *Crepis leontodontoides*. AVERY, PRISCILLA. *University of California Publications in Agricultural Sciences*, Vol. 6, No. 5, pp. 135-167. Berkeley, Cal. 1930.

The following crosses were studied cytologically in both somatic and meiotic phases :—

C. leontodontoides	(n 5)	X	*C. tectorum*	(n 4)
„ „		X	*C. parviflora*	(n 4)
C. capillaria	(n 3)	X	*C. leontodontoides*	(n 5)
C. leontodontoides	(n 5)	X	C. Marschallie	(n 4)
„ „		X	C. aurea	(n 5)

The author especially emphasizes three features of the F_1 hybrids, namely, the sharpness of distinction in morphology between the chromosomes of the parental sets, the conjugation of morphologically distinct chromosomes, and the variable amount of chromosome conjugation. The size differences between the parental chromosome complements were sufficient to permit recognition in the hybrids in both somatic and meiotic chromosomes.

The author assumes that various transformational processes resulting from fragmentation, union, translocation, inversion, deletion and duplication must have been responsible for the differences between the genoms of the species. These differences would cause the formation of a variable number of pairds of chromosomes which appeared in hybrid meiosis.

Alfalfa dwarf, a hitherto unreported disease. WEIMER, J. L. *Phytopathology*, Volume 21, No. 1, pp. 71-75. Lancaster, Pa. 1931.

A brief preliminary description of hitherto undescribed disease of alfalfa occurring in Southern California is given. Since the symptoms produced by the dwarf disease and by bacterial wilt are so similar that it is often difficult for one not familiar with both diseases to tell them apart, it seems desirable to compare rather definitely the symptoms of each. The following points should be helpful in distinguishing between these two diseases.

(1) Both wilt and dwarf cause a decided stunting of the tops of the plants as the diseases progress, although neither produces evident top symptoms in the earliest stages.

(2) In both diseases the stems become fewer, shorter, and more spindling after each cutting, until only a very few stems are produced, and these eventually die.

(3) Bacterial wilt causes stunted and abnormally shaped leaves that are usually paler in colour than those of healthy plants. In the dwarf disease the leaves become quite small but remain practically normal in shape and color until the death of the plant.

(4) Both diseases may produce wilting under certain conditions but this is not a constant or very conspicuous symptom of either disease.

(5) The root symptoms produced by the two diseases are very similar. The earliest stage that can be detected in roots affected with either disease is a slight yellowing of the wood just beneath the bark. This yellowing, which results largely from the formation of gum in the vessels, spreads until the entire active part of the xylem is more or less completely involved. The reddish-brown lesions in the bark and wood of roots affected with wilt, described and illustrated by Jone and McCulloch, have never been seen in roots affected with dwarf.

(6) In case of doubt the presence of the bacteria in the vessels of the roots of plants affected with wilt can easily be demonstrated in freehand sections by Gram's stain. No bacteria will be seen in similarly treated sections of roots having the dwarf disease.

Author's summary.

Beitrage zur kenntnis einiger Luzerne-Herkunfte, mit besonderer Berucksichtigung des Samenertrages. (Contributions to the knowledge of some lucernes of different origins, with special reference to their seed yield.) IFFLAND, TH. *Pflanzenbau*, Volume 7, No. 7, pp. 193-217. Berlin, 1931.

(1) *Flower colour.*—On this basis three groups may be recognised, (*a*) lucerne from Southern lands, (*b*) Cossack, Grimm, Italian and Hungarian lucerne, (*c*) German strains. Flower colour is to some extent correlated to the agricultural value of the strains in question. (2) *Leaf form*

data were of no value. (3) *Leaf colour.* Provence has a preponderance of light-coloured leaves, the hybrid lucernes a preponderance of dark-coloured leaves. (4) *Growth habit.* Provence tall and compact, hybrid lucernes, especially American strains, of medium height and very spreading. (5) *Proportion of stem.* Regulated partly by the standing distance of the plants. Always a higher proportion in Provence. (6) *Plant weight* greater in dark-leaved plants. (7) *Seed weight* gave similar correlation. (8) *Growth rhythm.* Provence showed vigorous shooting after each cut, but earlier suspension of growth. (9) *Stand density* lower in German lucernes; hard-coatedness may be of importance here. (10) *Disease Peronospora Trifoliorum* occurred in some strains. (11) *Winterhardiness* correlated to leaf colour.

Relations between above characters and seed yield:—Plants with dark leaves yield more seed. Higher yield expected from late and spreading plants. Hybrid-coloured and pale violet plants gave the highest yield. Positive correlation between plant weight and seed yield and between plant weight stem ratio. Trials for influence of standing distance gave various results according to origin. Best yield was obtained from one year-trial, rows 40 cms. apart and plants 20 cms. apart.

Uber Xenien bei Leguminosen (On Xenias in Leguminosae). TSCHERMAK, ERICH. *Xeits f. Zuchtung. A Pflanzenzuchtung*, Vol. 16, No. 1, pp. 73—81.

Berlin, 1931. (N. B. Xenia appearances in seed, fruit, or maternal organ of characters belonging to the male parent.)

Xenias may be classified in two groups; (*a*) seed Xenias, *i.e.*, patroclinal alterations of the colour, form, size and chemistry of seeds, (*b*) fructification xenias, *i.e.*, increased growth of receptacles and patroclinal alterations of fruit form and chemistry.

The following seed xenias observed by the author are described in detail: seed xenias in peas, beans, lupins, vetches, etc., in addition size xenias after the hybridization of certain bean races, and finally fructification xenias in beans and other plants.

The author emphasises the utility of colour xenias and seed heterogeneity for breeding as a correlative index for estimating certain other seed qualities and for estimating the degree of cross pollination in self-fertilising plants.

The occurrence of a secondary segregation in addition to the chief segregation in seed colour is proved and attributed to polymeric difference in catalytic-cumulative factors besides a chief colour factor.

The crossing of two bean races led to the production of size xenias and consecutive seed heterogeneity; whilst the crossing of others produced no xenias, and seed homogeneity was observed in the individual plants and, from F_2 on, segregation into individuals of different seed sizes.

A distinction is made between independent and dependent types of inheritance of seed characters.

IMPERIAL AGRICULTURAL BUREAUX.

The Imperial Agricultural Bureaux have, during the last few months, undertaken the periodical issues of abstracts (or extended titles) of current literature in the branches of science in which they are interested. Brief particulars are as follows:—

Title.	Issued by the Imperial Bureau of.	How issued.	Price.	
			Annual subscription.	Single copies.
			s.	*s.* *d.*
Plant Breeding Abstracts.	Plant Genetics, Cambridge, England.	Printed (quarterly).	5	1 6
Herbage Abstracts .	Plant Genetics (Herbage Plants) Aberystwyth, Wales.	Printed (quarterly).	5	1 6
Technical Communications.	Soil Science, Rothamsted, Harpenden, Herts, England.	Duplicated .	Various .	....
Horticultural Abstracts.	Fruit Production, East Malling Kent, England.	Printed (quarterly).	5	1 6
Veterinary Bulletin .	Animal Health, Weybridge, England.	Printed (quarterly at present).	20	7 6
Animal Nutrition Abstracts and Reviews.	Animal Nutrition, Rowett Research Institute, Bucksburn, Aberdeen, Scotland.	Printed (quarterly).	21	6 0
(*a*) Quarterly Bulletin	Animal Genetics, Edinburgh.	Printed (quarterly).	Free at present 5 *s.* p. a. next year.	1 6
(*b*) Monthly list of References.		Duplicated (monthly).	Free at present .	....

The Rothamsted list of extended titles will include the titles of all articles which the Bureau have indexed on their cards so that any research worker who takes in this journal will have at hand a complete index of the current literature available at Rothamsted. The same is true of the Imperial Bureau of Animal Genetics except that certain references collected for visiting research workers to the Department of Animal Genetics and not of interest to the general worker in this field are omitted. Thus the list of titles is to some extent selected, but the widest possible range is covered with regard to the needs of the correspondent of the Bureau.

It will be noted that all the publications have been priced. This is necessary as there is clearly a limit to which the Bureaux can undertake the free distribution of their literature. On the other hand arrangements have been made to supply a considerable number of copies free varying with the different publications.

The number of free copies of Animal Nutrition abstracts and reviews is strictly limited. This journal is a joint effort on the part of the Executive Council of the Imperial Agricultural Bureaux, the General Medical Research Council and the Reid Library at the Rowett Institute, Aberdeen. The scientific reason for this joint effort is apparent. On questions of nutrition it is impossible to draw a strict line between the Research undertaken primarily for human benefit and that undertaken primarily for the benefit of stock. Both those who are working on human problems and on stock problems are interested in each others progress in research. As three different bodies are financing this venture it was found necessary to limit the number of free copies issued.

Concurrently with the issue of these abstracting journals papers will be issued by all the Bureaux on particular technical problems or containing bibliographies on special research questions as hitherto.

PLANT BREEDING ABSTRACTS.

The Imperial Bureau of Plant Genetics has begun to issue a publication entitled "Plant Breeding Abstracts" in which all the more important current publications dealing with plant-breeding and the genetics of crop plants are listed. The references are classified according to subject and each reference is followed by an abstract indicating the subject matter of the paper and the results obtained. The papers are divided into two halves, those published in the British Empire and those published in foreign countries. Papers written in foreign languages are usually abstracted somewhat more fully than papers in English.

"Plant Breeding Abstracts" is issued quarterly and Vol. I, No. 3 which was published on April 1st, 1931, contains 197 references covering 52 pages.

The annual subscription for the publication is at present Rs. 5 post free, single copies being obtainable at the price of Rs. 1-6. Subscriptions should be sent to the Deputy Director Imperial Bureau of Plant Genetics, School of Agriculture, Cambridge, England.

LIST OF PUBLICATIONS RELATING TO SOILS AND FERTILIZERS.

We have received from the Director, Imperial Bureau of Soil Science, Rothamsted Experimental Station, Harpenden, 2 copies of the first issue of the 'List of Publications relating to Soils and Fertilizers'—January to April, 1931. This useful publication (An. Sub. 10s.), which the Bureau proposes to issue regularly in future, consists of short notices of all current papers and phamphlets indexed by the Bureau, numbering between 1,500 and 2,000 a year. Each entry contains the title of the paper in English, an abstract of two or three lines—virtually an expansion of the title—, and the indexing number according to the system of "Classification Decimale." Interested research workers in India who are not receiving copies of this publication are invited to communicate with the Council.

WOODHOUSE MEMORIAL PRIZE.

In memory of Mr. E. J. Woodhouse, Late Economic Botanist and Principal of Sabour Agricultural College, who was killed in action in France in 1917, a prize in the form of a silver medal and books of a combined value of Rs. 85 will be awarded to the writer of the best essay on a subject of botanical interest to be selected from the list noted below. The length of the essay should not exceed 4,000 words.

The competition is open to graduates of Indian Universities and to Diploma holders and Licentiates of recognised Agricultural Colleges in India who are not more than 30 years of age on the date of submission of their essays.

Papers should be forwarded to the Director of Agriculture, Bihar and Orissa, Patna, before November 1st, 1931.

Failing papers of sufficient merit no award will be made.

G. S. HENDERSON,

Director of Agriculture, Bihar and Orissa.

List of subjects for 1931 prize:

1. The relative value of inbreeding and out-breeding in crop improvement.
2. The problem of Fodder Crops in India.
3. Virus diseases.
4. Symbiosis and plant growth.
5. The study of correlations and their economic bearing in the science of plant breeding.
6. The inter-relations between vegitative propagation and seed reproduction.

ORIGINAL ARTICLES

NITROGEN RECUPERATION IN THE SOILS OF THE BOMBAY PRESIDENCY, PART II.

BY

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AND

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(Received for publication on 5th August 1931.)

I. Introduction.

In the year 1925 a memoir was published with the title "Nitrogen Recuperation in the Soils of the Bombay Deccan, Part I". [Sahasrabuddhe and Daji, 1925.] In this publication after making a mention of the work of the various investigators on the recuperation of nitrogen by soils, details of experiments done on the soil of the Bombay Deccan were described. The experiments were conducted in the laboratory on the medium black soil of the Deccan, taken at the end of the hot weather, kept dry and then exposed to varying conditions of light, water and temperature. The results were summarised as given below :—

(1) When water is added to the soil within ten days a large quantity of nitrogen is fixed and this goes on increasing till about thirty-five days and then slowly begins to decrease.

(2) Up to 30 per cent. of water, the larger the quantity of the water, the higher is the nitrogen fixed.

(3) The fixation of nitrogen and nitrification are higher at 40°C. than at lower temperature.

(4) Increase in nitrogen takes place both in the presence and absence of light.

(5) The addition of lime to the soil (already containing enough of lime) does not show any advantage over the original soil in increasing nitrogen fixation, but it facilitates nitrification.

(6) If the soil which has fixed the highest quantity of nitrogen after being moistened, gets dried up and then gets moistened again, the nitrogen increases further for four or five weeks more and then begins to go down. Repeated drying, however, does not increase the nitrogen contents beyond a certain limit.

(7) If the soil is heated to 100°C. it loses a small quantity of nitrogen. This, however, is soon made up, if enough water is added to it, and the total amount of nitrogen fixed in the heated soil is found to be higher than that in the unheated soil.

This paper, which forms Part II, is only a continuation of Part I. It gives the results of experiments done with different typical soils of the Bombay Presidency. It also records the results of experiments done to find out the effect on nitrogen recuperation of added (*a*) lime as calcium carbonate, (*b*) phosphatic substances, (*c*) organic matter and (*d*) alkali salts.

The soils alone or with additional substances were kept at 35°C. in an incubator. It has been shown in Part I that the higher the temperature the higher is the nitrogen recuperation up to 40°C. This temperature is a little higher than the temperature to which soils in the Bombay Deccan are raised. The records (Manjri Dry Farm) show that the highest daily temperatures of soils during the hot season vary from 30°C. to 37°C. and it was hence that during all the experiments soils were maintained at the constant temperature of 35°C.

It was also observed in Part I that for medium black soil the higher the water contents up to 30 per cent. the higher was the recuperation. The water holding capacity of the medium black soil as mentioned further on (page 636) is 91·83 per cent. Thirty per cent. water is, therefore, nearly one-third the water holding capacity. In order to obtain comparative results it was necessary to have water with a fixed proportion to the water-holding capacity of the soils. All the soils had, therefore, water equal to one-third the water-holding capacity.

General plan of experiments.

About 1,000 grams of air-dry soil from the stock material were taken in a brass tray 20·5 cm. in diameter and 5·5 cm. in height. Nitrogen-free distilled water was added to the soil in the form of a thin spray to make up one-third of the water-holding capacity. The soil was slightly stirred and evenly mixed up with water. This formed the control pot. Similar trays with the same quantity of the soil were taken up for different treatments. When soluble materials were to be added they were dissolved in water and the solution was added to the soil in the form of a spray and finally extra water was added to make up one-third the water-holding capacity. In the case of insoluble substances the material was first thoroughly mixed with the soil and then water was added.

Before incubating the soil trays were weighed and every day water was added by spray to keep up the original moisture content. All the trays were carefully incubated at 35°C.

In the study of the recuperation of nitrogren the following determinations were made on the first day and on every 14th day for six weeks.

(1) Organic and ammonical nitrogen.
(2) Nitrite nitrogen.
(3) Nitrate nitrogen.
(4) Moisture (at 98°C. in a steam oven).

Methods of analysis used were the same as given in Appendix in Part I.

II. Soils used.

The soils used in the experiments represent important types. They differ from each other sufficiently to be classed separately. A short description and analytical figures of each are given below. They help in properly interpreting the results of the experiments.

Description of Soils.

Medium black soil :—It is derived from the Deccan trap. The sample experimented upon was collected near Poona. It had been under *bajri* or *jowar* for years without any leguminous crop and at least for fifteen years previous to the experiments it had not received any manure. It had never been irrigated.

Deccan River Silt :—This is also derived from the washing down of the decomposed Deccan trap. The place (near Poona) where the soil was collected is flooded once or twice every year during the rainy season. The land was never under cultivation. It is used in gardens to replace old soil and to fill earthen pots.

Goradu soil :—This is a typical sandy soil well known in Gujarat. It was collected at Nadiad. The plot was manured every year with about 1,000 lbs. of farmyard manure. Tobacco is the only crop grown on this plot so far.

Laterite soil :—This is derived from laterite rock. The soil used for experiments was collected from a field under garden crop near Belgaum. It was heavily manured.

Table I.

Chemical Composition.

——	Medium black soil	River silt soil	Goradu soil	Laterite soil
	Per cent.	Per cent.	Per cent.	Per cent.
Moisture (given off at 98°C.) . . .	6·60	6·30	1·80	2·68
Loss on ignition (excluding moisture given off at 98°C.)	11·40	9·12	2·72	12·07
Organic matter	..	1·88	1·48	3·79

TABLE I—*contd.*

Chemical Composition—contd.

—	Medium black soil	River silt soil	Goradu soil	Laterite soil
	Per cent.	Per cent.	Per cent.	Per cent.
Sand (acid insoluble)	58·40	62·51	67·40	55·82
Iron oxide (Fe_2O_3)	11·90	10·72	4·00	15·20
Alumina (Al_2O_3)	6·50	10·76	1·46	14·34
Total lime (CaO)	4·73	1·05	1·85	0·41
Magnesia (MgO)	1·60	0·40	0·30	0·90
Potash (K_2O)	0·40	0·17	0·39	0·31
Phosphoric acid (P_2O_5)	0·07	0·089	0·21	0·16
Total nitrogen	0·048	0·086	0.076	0·159
Carbonate Lime (CaO)	4·45	0·73	1·32	0·25
Equal to calcium carbonate . . .	7·96	1·30	2·36	0·44

TABLE II.

Water-soluble constituents.

—	Medium black soil	River silt soil	Goradu soil	Laterite soil
	Per cent.	Per cent.	Per cent.	Per cent.
Total soluble salts	0·05	0·08	0·09	0·05
Containing :—				
Total carbonate	0·014	0·011	0·011	0·003
Sodium carbonate	*Nil*	*Nil*	*Nil*	*Nil*
Total chlorine	0·0035	0·007	0·0035	0·0035

The percentage of total soluble salts is small and there is no sodium carbonate in any of these soils.

The mechanical constituents as determined by the International Method are as given below :—

TABLE III.

Nomenclature of soil separates	Mean diameter of the soil particles in millimeter	Medium black soil	River silt soil	Goradu soil	Laterite soil
		Per cent.	Per cent.	Per cent.	Per cent.
Sand	2·0—0·2	5·22	4·71	4·48	4·62
Fine sand	0·2—0·02	9·04	35·97	67·25	11·68
Silt	0·02—0·006	14·50	17·50	12·00	11·59
Fine silt	0·006—0·002	17·00	11·00	4·50	18·50
Clay	Below 0·002	33·00	16·00	9·00	42·00

Comparative capillary power of the soils used varied as under. Readings were taken at many stages but only a few are given in the table.

TABLE IV.

Period	Medium black soil	River silt soil	Goradu soil	Laterite soil
After	cms.	cms.	cms.	cms.
1 hour	6·7	15·2	19·7	12·2
2 hours	8·5	20·3	26·6	16·8
6 hours	13·0	33·2	43·3	27·7
1 day	22·8	52·0	68·5	44·0
4 days	36·5	72·8	98·7	65·2
8 days	44·7	85·5	112 5	77·5

The "sticky point" [Keen and Coutts, 1928] and water-holding capacity of the soils gave the following figures :—

TABLE V.

Type of soil	Moisture at 'sticky' point	Water-holding capacity
	Per cent.	Per cent.
1. Medium black soil	57·73	91·83
2. River silt soil	43·59	69·99
3. Goradu soil	26·20	41·59
4. Laterite soil	42·88	68·19

pH value of the soils as determined by Potentiometer were found to be as follows :—

TABLE VI.

—	Medium black soil	River silt soil	Goradu soil	Laterite soil
pH value	8·35	8·18	8·22	5·99

III. EFFECT OF ADDITION OF LIME.

It is well-known that lime is one of the essential plant food constituents and it is observed that addition of lime to some soils has a beneficial effect on plant growth. Russell [1930] has shown that the gain in nitrogen is much influenced by the amount of calcium carbonate present in the soil. Brown [1911] observed that calcium carbonate increased the nitrifying and nitrogen fixing power of soils. Others [Waksman and Karunkar, 1924] have observed that the addition of calcium carbonate to the soils increased the nitrogen-fixing power of soils.

In Part I, it was observed that the addition of lime to the soil (already containing enough of lime) does not show any advantage over the original soil in increasing nitrogen fixation but it facilitates nitrification. In order to ascertain the effect of additional lime on soils with different percentages of original lime, experiments were done on Goradu soil from Nadiad, River silt from Poona and Laterite soil from Belgaum by adding 3 and 5 per cent. of calcium carbonate.

Water was made up to one-third of the water-holding capacity and the treated trays along with controls for each soil were incubated at 35°C.

TABLE VII.

Milligrams of total nitrogen per 100 grams of soil on oven-dry basis.

Soil	Calcium carbonate added	1st day	14th day	28th day	42nd day
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Goradu (control)	*Nil*	77·92	82·88	81·91	80·73
„ with lime added .	3·00	75·58	78·11	82·37	81·69
„ „ .	5·00	74·04	76·18	78·57	80·76
River silt (control) . .	*Nil*	86·17	..	91·01	89·15
„ with lime added . .	3·00	83·58	91·37	91·69	84·05
„ „ .	5·00	81·86	93·58	91·04	90·31
Laterite (control) . . .	*Nil*	163·34	164·96	166·26	166·89
„ with lime added .	3·00	158·47	157·12	169·12	166·88
„ „ .	5·00	155·22	155·20	166·50	171·63

Taking all the soils experimented upon and taking the highest figures reached by each soil, in six weeks it is distinctly seen that the higher the percentage of lime in the soil the higher is its power of recuperating nitrogen as shown in the following table.

The calculation is done as under :—Goradu soil gave 77·92 milligrams of nitrogen on the first day and the highest point reached during the experimental period was 82·88 milligrams. This means 4·96 milligrams of increase or 6·36 per cent. over the original. All the figures in Table VIII are obtained in the same fashion.

TABLE VIII.

Soil	Lime as $CaCO_3$	pH value	Nitrogen fixed per 100 grams of soil over the original nitrogen
	Per cent.	Per cent.	Per cent.
Medium black soil	7·96	8·35	21·17*
Goradu soil	2·36	8·22	6·36
River silt soil	1·30	8·18	5·6
Laterite soil	0·44	5·99	2·17

*This figure is obtained from Table XIII for medium black soil control on page 641.

The experiments with additional lime to these soils, clearly bring out the fact, as shown in the table below, that the smaller the proportion of original lime in the soil the greater is the beneficial effect of additional lime in increasing the nitrogen recuperation power of the soil.

The figures for Table IX are obtained as under :—Taking Goradu soil to illustrate, we have in Table VIII an increase of nitrogen of 6·36 per cent. in the soil when no outside lime is added. When 3 per cent. lime is added we get an increase from 75·58 to 82·37 (Table VII), *i.e.*, an increase of 8·98 per cent. Therefore, the effect of additional lime is the difference between 8·98 and 6·36. This is equal to 2·62 which is the figure given under 3 per cent. lime added in Table IX. All the figures in Table IX are similarly calculated. This long calculation is necessary to show the exact effect of lime.

TABLE IX.

Soil	Original lime present as calcium carbonate	Milligrams of nitrogen fixed over that in the control	
		3 per cent. lime added	5 per cent. lime added
[Sahasrabuddhe and Daji, 1925]	Per cent.	Per cent.	Per cent.
Medium black soil	7·96	*Nil*	*Nil*
Goradu soil	2·36	2·62	2·71
River silt soil	1·30	4·09	8·70
Laterite soil	0·44	4·55	8·40

As shown in Part I, the Medium black soil which already contains a high proportion of lime is not benefited at all by additional lime while all the other soils are benefited. In Goradu soil with 2·36 per cent. of original lime, addition of 3 per cent. shows some increase in the power of recuperation but 5 per cent. addition does not show any distinct advantage over 3 per cent. because the addition of 3 per cent. is enough to make up the required proportion of lime and the extra 2 per cent. has, therefore, no effect.

It was pointed out in Part I [Sahasrabuddhe and Daji, 1925], that the addition of lime increased the nitrifying power of the soil. The same tendency was shown by the Goradu, River silt and Laterite soils, when treated with lime.

IV. Effect of Phosphatic Substances.

Phosphoric acid is one of the important plant food constituents. In a suitable form it is found to be beneficial to crops and to small organisms. The addition of phosphorus to a soil has been found to increase the amount of nitrogen fixed. Bear [1917] gives the following amount of nitrogen fixed with and without phosphorus.

Table X.

—	Without phosphorus Nitrogen fixed	With phosphorus Nitrogen fixed
	Milligrams	Milligrams
Soil without lime	0·3	2·0
Soil with lime 0·05 per cent.	0·6	4·6

Russell [1930] mentions that on clay pastures dressings of basic slag have been found to increase the nitrogen content of the soil. Four soils, namely, the Medium black, River silt, Goradu and Laterite were experimented upon to find the effect of phosphatic substances on the nitrogen recuperation power of soils. The phosphatic substances used were (1) di-potassium mono-hydrogen phosphate which is easily soluble in water and neutral in reaction, (2) superphosphate which contains soluble phosphate and is acid in reaction, and (3) tricalcic phosphate (pure chemical) which is very slightly soluble and slightly alkaline in reaction. Each of the substances was added in two portions to each of the four soils. The quantities were equal to 0·01 per cent. and 0·015 per cent. of phosphoric acid (P_2O_5) per 100 grams of soil on oven-dry basis. All the soils had water equal to one-third the water-holding capacity and all the samples were maintained at 35°C.

The first trial of phosphoric acid with regard to the nitrogen recuperation

power of the soil was made with 0·0075 per cent. and 0·01 per cent. of P_2O_5 in the form of superphosphate on four soils and the results obtained are given below :—

TABLE XI.

Milligrams of nitrogen per 100 grams of soil on oven-dry basis.

Soil	1st day	14th day	28th day	42nd day
	Total nitrogen			
Medium black soil (control)	51·54	60·29	61·57	62·45
„ with 0·0075 per cent. P_2O_5		54·22	64·21	60·30
„ „ 0·01 per cent. P_2O_5		55·08	64·62	67·59
River silt (control)	86·17	...	91·01	89·15
„ with 0·0075 per cent. P_2O_5		94·92	105·44	91·22
„ „ 0·01 per cent. P_2O_5		96·10	108·27	94·65
Laterite soil (control)	163·34	164·96	166·26	166·89
„ with 0·0075 per cent. P_2O_5		166·80	165·75	156·08
„ „ 0·01 per cent. P_2O_5		169·90	170·74	158·74
Goradu soil (control)	77·92	82·88	81·91	80·73
„ with 0·0075 per cent. P_2O_5		85·94	79·80	81·10
„ „ 0·01 per cent. P_2O_5		86·88	80·64	81·63

It is clear from the above table that if phosphoric acid, in the form of superphosphate, is added to soils, their nitrogen recuperation power is increased. In the quantities used, the larger quantity of phosphoric acid has a better effect than the smaller quantity. Actual percentage increase over the control in each soil is as given below :—

TABLE XII.

Percentage increase over the control.

—	Medium black soil	River silt soil	Laterite soil	Goradu soil
Original P_2O_5	0·07	0·089	0·16	0·21
Soil with added 0·0075 per cent. P_2O_5	3·41	16·75	*Nil*	3·93
Soil with added 0·01 per cent. P_2O_5	9·97	20·03	2·36	5·13

The Laterite soil which is acidic is not expected to show any improvement with the addition of acid substances. The River silt has been much benefited. With other two soils the smaller the original P_2O_5 the better is the effect of additional P_2O_5.

All the four soils mentioned above were experimented upon with P_2O_5 in other forms.

Each soil was treated with 0·01 per cent. and 0·015 per cent. of P_2O_5 in the form of potassium phosphate and tricalcic phosphate. The results are given below :—

TABLE XIII.

Milligrams of total nitrogen in 100 grams of soil on oven-dry basis.

Soil	Added P_2O_5	1st day	14th day	28th day	42nd day
	Per cent.				
Medium black control	*Nil*	51·54	60·29	61·57	62·45
„ „ with potassium phosphate	0·010		59·72	60·99	56·98
	0·015		67·40	59·40	58·25
„ „ with tricalcic phosphate	0·010		55·96	66·82	59·38
	0·015		55·56	68·90	61·61
River silt control	*Nil*	86·17	...	91·01	89·15
„ „ with potassium phosphate	0·010		96·80	80·64	80·21
	0·015		105·14	98·18	86·36
„ „ with tricalcic phosphate	0·010		91·89	106·33	91·18
	0·015		95·31	108·62	95·33
Laterite silt control	*Nil*	163·34	164·96	166·26	166·89
„ „ with potassium phosphate	0·010		171·95	161·14	150·14
	0·015		172·34	163·91	151·33
„ „ with tricalcic phosphate	0·010		167·42	160·09	161·62
	0·015		175·26	163·76	161·93
Goradu control	*Nil*	77·92	82·88	81·91	80·73
„ with potassium phosphate	0·010		80·44	84·07	80·77
	0·015		86·24	84·47	81·60
„ with tricalcic phosphate	0·010		78·43	79·75	82·88
	0·015		84·17	79·92	81·96

These again point to the fact that addition of phosphoric acid increases nitrogen recuperation power of the soil and the higher the quantity added the higher is the increase. The percentage of increase over the control is shown by taking the highest figure reached in six weeks for 0·015 per cent. of phosphoric acid added to each soil.

TABLE XIV.

Percentage increase over the increase in the control.

Soil	Potassium phosphate 0·015 per cent. P_2O_5 added	Tri-calcic phosphate 0·015 per cent. P_2O_5 added
Medium black containing 0·07 per cent. original P_2O_5	9·61	12·51
River silt containing 0·089 per cent. original P_2O_5	16·40	20·44
Laterite containing 0·16 per cent. original P_2O_5	3·34	5·12
Goradu containing 0·21 per cent. original P_2O_5	4·31	1·66

The River silt responds very well to the addition of P_2O_5. The Medium black soil which contains a small proportion of P_2O_5 also responds to the addition of P_2O_5 but the other two soils which contain enough of P_2O_5, do not much respond. The tri-calcic phosphate on the whole shows a better effect than potassium phosphate.

Comparing P_2O_5 in the form of superphosphate with that of tri-calcic phosphate the comparative results are as given below :—

TABLE XV.

Percentage increase in nitrogen recuperation over the increase in the control.

Soil	Superphosphate 0·01 per cent. P_2O_5 added	Tri-calcic phosphate 0·01 per cent. P_2O_5 added
Medium black soil containing 0·07 per cent. original P_2O_5	9·98	8·48
River silt containing 0·089 per cent. original P_2O_5	20·03	17·78
Laterite containing 0·16 per cent. original P_2O_5	2·36	0·32
Goradu soil containing 0·21 per cent. original P_2O_5	5·13	*Nil*

Superphosphate seems to have the best effect but tri-talcic phosphate which is insoluble is next to superphosphate. Potassium phosphate, although soluble, shows very little effect especially in such low proportions as 0·010 per cent. With 0·015 per cent. it comes up sufficiently high but not quite as much as tri-calcic phosphate. The effect of superphosphate and tri-calcic phosphate may be partly due to the lime present in these, but the effect cannot be chiefly attributed to lime. The Medium black soil contains a good amount of original lime but a small quantity of P_2O_5 ; and it is more benefited than other soils which are poorer in lime and richer in P_2O_5.

V. Effect of addition of organic matter.

Organic matter is a very important constituent of the soil, especially in India where the exposure of the soils to the hot sun for a long period, is likely to remove a good amount of organic matter.

Nitrogen contents of the soils cannot increase by themselves. Russell [1927] says that increases are possible only when carbon is increased. He also mentions that Pleiffer and Blank did not get any beneficial effect by adding sugar. Hutchinson [1918] by the addition of sugar, straw, plant, roots, etc., and Joshi [1919] by the addition of glucose, cane sugar or filter paper have observed that the nitrogen contents of sand or soil may be appreciably increased. Joshi also shows that the nitrogen fixed in this way does not nitrify within four weeks. Allison [1927] observed that addition of straw, fresh stable manure had an adverse effect on nitrification in the soil for sometime.

In the experiments given below cane sugar was added to the soils as organic matter. As a practical measure addition of cane sugar to the soil is out of the question but for experimental work cane sugar was selected in order to avoid all the factors except soluble carbohydrate material The object was to see what effect was produced on different soils if the same quantities of soluble carbohydrates were added to them. And the simple answer to the question could be obtained by adding a simple substance like cane sugar.

Goradu, River silt and Laterite were the three soils selected for experiments. They contain different proportions of organic matter. Cane sugar was added in solution in two proportions—two per cent. and four per cent. Water was added to make up to one-third the water-holding capacity of each soil and all the samples were incubated at 35°C.

TABLE XVI.

Milligrams of total nitrogen per 100 grams of soil on oven-dry basis.

Soil	Original organic matter	Added sugar	1st day	14th day	28th day	42nd day
		Per cent.				
Goradu	1·48	*Nil*	77·92	82·88	81·91	80·73
Do.	1·48	2	75·18	96·82	91·84	90·40
Do.	1·48	4	74·11	96·00	94·96	95·95
River silt	1·88	*Nil*	86·17	..	91·01	89·15
Do.	1·88	2	84·46	94·80	104·65	96·50
Do.	1·88	4	82·76	94·84	104·76	95·77
Laterite	3·79	*Nil*	163·34	164·96	166·26	166·89
Do.	3·79	2	159·12	159·08	162·86	167·22
Do.	3·79	4	156·85	156·10	163·16	166·78

Addition of 2 per cent. sugar shows a beneficial effect in increasing nitrogen fixation power and a further addition of 2 per cent. shows a further small advantage with the three soils, under experiment. If the highest figures reached in six weeks are taken the per cent. increases over the increase in the controls are as follows :—

TABLE XVII.

Percentage increases over the increase in the control.

——	Goradu soil	River silt	Laterite
With 2 per cent. sugar	22·42	14·98	2·93
With 4 per cent. sugar	23.17	15·10	4·16
Original organic matter	1·48	1·88	3·79

The smaller the proportion of original organic matter the greater is the effect of added organic matter.

The effect of added sugar on the nitrification in the soils is deleterious at least for six weeks as will be seen from the following table :—

TABLE XVIII.

Milligrams of nitric nitrogen per 100 grams of soil on oven-dry basis.

Soil	Added sugar	1st day	14th day	28th day	42nd day
	Per cent.				
Goradu	*Nil*	1·65	2·73	3·33	3·22
Do.	2	0·60	0·38	0·39	0·24
Do.	4	0·64	0·42	0·37	0·20
River Silt . . .	*Nil*	0·94	—	4·13	5·26
Do.	2	0·94	0·37	0·34	0·20
Do.	4	0·94	0·33	0·43	0·23
Laterite . . .	*Nil*	1·02	4·10	5·80	6·25
Do.	2	1·02	0·17	0·13	0·17
Do.	4	1·02	0·12	0·16	0·17

VI.—EFFECT OF ALKALI SALTS.

There are several tracts in the Bombay Presidency where alkali salts are found in the soils. In some places the quantities of the alkali salts are so much that the soils produce but a very poor crop or sometimes none at all.

Greaves [1922] and his associates and also Singh [1918] have found that the alkali salts like the carbonate, the sulphate and the chloride of sodium in limited quantities, stimulate nitrogen fixation but beyond certain concentrations they become toxic. Much work has been done on this particular question but the results obtained are not in all cases exactly the same.

The most important of the alkali salts are the carbonate, the sulphate and the chloride of sodium. In the experimental work done these salts were separately tried in two proportions on the following soils. The soils contain very small quan-

tities of soluble salts and none of them showed any traces of sodium carbonate which is strongly alkaline.

TABLE XIX.

—	Total soluble salts. Percentage on oven-dry basis
Medium black soil	0·086
River silt soil	0·085
Goradu soil	0·092
Laterite soil	0·051

The Medium black soil was treated with sodium carbonate. The Goradu and the Laterite soils were treated with all the three alkali salts in the proportions given below :—

TABLE XX.

—	Total soluble salts. Percentage on oven-dry basis
Sodium carbonate	0·01
Do. do.	0·02
Sodium sulphate	0·02
Do. do.	0·04
Sodium chloride	0·03
Do. do.	0·06

After making up the necessary porportion of water the trays were incubated. The results were as follows :—

TABLE XXI.

Milligrams of total nitrogen in 100 grams of soil on oven-dry basis.

Soil	Quantity of salt	1st Day	14th day	28th day	42nd day
	Per cent.				
Medium black. . .	*Nil*	51·54	60·29	61·57	62·45
Medium black with sodium carbonate.	0·01		56·53	57·73	55·44
	0·02		56·38	57·60	53·96
Goradu	*Nil*	77·92	82·88	81·91	80·73
Goradu with sodium carbonate.	0·01		77·75	79·86	81·22
	0·02		79·56	80·04	79·93
Goradu with sodium sulphate.	0·02		78·54	79·75	81·36
	0·04		79·35	79·56	81·08
Goradu with sodium chloride.	0·03		78·92	78·39	81·05
	0·06		78·64	78·81	80·41
Laterite	*Nil*	163·34	164·96	166·26	166·89
Laterite with sodium carbonate.	0·01		163·42	164·21	165·57
	0·02		163·95	163·48	163·64
Laterite with sodium sulphate.	0·02		165·11	161·93	166·74
	0·04		164·22	161·15	163·69
Laterite with sodium chloride.	0·03		163·75	164·64	168·33
	0·06		159·23	158·32	162·18

The effect of the alkali salts will be easily understood if the percentage variation *plus* or *minus* from the per cent. increase in the control is calculated as in the

following table. Only the highest figures obtained in six weeks are taken for calculation.

TABLE XXII.

Percentage variation from percentage increase of nitrogen in the control.

Soil	Sodium carbonate		Sodium sulphate		Sodium chloride	
	0·01 Per cent.	0·02 Per cent.	0·02 Per cent.	0·04 Per cent.	0·03 Per cent.	0·06 Per cent.
Medium black . . .	—9·16	—10·0	—	—	—	—
Goradu	—2·13	—3·64	—1·95	—2·31	—2·35	—3·17
Laterite	—0·82	—1·80	—0·1	—1·64	—0·85	—2·88

From these figures it is clear that only sodium chloride in the proportion of 0·03 per cent. had no deleterious effect on Laterite soil but with this exception all the salts in both the proportions showed a deleterious effect on the soils in their nitrogen recuperation power. It is also clear that the higher the proportion of the salt, the greater is the effect. Out of the three salts, sodium carbonate had the worst and sodium chloride the least effect.

The greatest effect is produced on the Medium black soil which contains the highest percentage of lime while the Laterite which has the smallest proportion of lime and which is distinctly acidic as indicated by its pH value has the least deleterious effect.

TABLE XXIII.

Percentage variation from per cent. increase of nitrogen in the control.

Soil	Lime as $CaCO_3$ present originally in the soil	pH value.	Per cent. variation from per cent. increase of nitrogen in the control with 0·02 per cent. sodium carbonate
Medium black	7·96	8·35	—10·0
Goradu soil	2·36	8·22	—3·64
Laterite soil	0·44	5·99	—1·80

No effect of these salts favourable or unfavourable was produced on the nitrifying power of the soil.

The experiments with the River silt soil require separate mention because the results are not in all respects in the same direction as those of other soils. When the River silt soil was treated with the alkali salts the following results were obtained :—

TABLE XXIV.

Milligrams of total nitrogen per 100 grams of soil on oven-dry basis.

Soil	Quantity of salt per cent.	1st day	14th day	28th day	42nd day
River silt	*Nil*	86·17	..	91·01	89·15
„ with sodium carbonate . .	0·01		95·13	94·61	97·28
	0·02		94·07	92·93	98·22
„ with sodium sulphate . .	0·02	86·17	87·79	86·03	92·06
	0·04		90·79	88·44	86·82
„ with sodium chloride . .	0·03	86·17	95·02	97·85	95·40
	0·06		94·78	94·98	99·16

In the case of the River silt except with 0·04 per cent. sodium sulphate where practically no effect is produced, the addition of alkali salts instead of producing a deleterious effect has stimulated the soil to fix nitrogen as shown below :—

TABLE XXV.

Per cent. increase of nitrogen over the increase in the control.

Soil	Sodium carbonate		Sodium sulphate		Sodium chloride	
	0·01 per cent.	0·02 per cent.	0·02 per cent.	0·04 per cent.	0·03 per cent.	0·06 per cent.
River silt	6·98	7·92	1·15	—0·24	7·5	8·95

Sodium carbonate and sodium chloride have distinctly stimulated the River silt to fix nitrogen and the higher quantity has given greater stimulation. It means that the quantities of alkali salts added were not sufficient to produce a bad effect on the River silt. In these experiments the alkali salts did not show any effect on the nitrifying power of the soil.

Summary of Conclusion.

1. As regards the soils experimented upon, the higher the percentage of lime in the soil, the higher is the nitrogen recuperation power of the soil. The smaller the proportion of original lime in the soil the greater is the beneficial effect of additional lime upto a certain limit in increasing the nitrogen recuperation power of the soil.

2. Additional lime always increases nitrification.

3. When superphosphate is added to soil its nitrogen recuperation power is increased except in the case of Laterite soil which has an acidic reaction. In the quantities used the larger the quantity of superphosphate added the better is the effect.

4. Similar results are obtained by the addition of tri-calcic phosphate or potassium phosphate.

5. The smaller the quantity of original phosphoric acid in the soil the better is the effect of additional phosphoric acid.

6. Out of the three forms used in supplying phosphoric acid, superphosphate proved to be the best (except on acid soil), tri-calcic phosphate stands next but not much below the superphosphate. Potassium phosphate stands third.

7. Addition of 2 per cent. of soluble organic matter like sugar has a good effect on nitrogen recuperation of soil. Further addition in the case of the soils experimented upon does not show much advantage. The effect produced is higher with soils containing smaller quantities of original organic matter than with those containing larger quantities of original organic matter.

8. Addition of sugar has a deleterious effect on the nitrifying power of the soil at least for sometime.

9. The alkali salts—sodium carbonate, sodium sulphate and sodium chloride—when added to Medium black soil of the Deccan, Goradu and Laterite soils show a deleterious effect on the nitrogen recuperation power of these soils. Sodium carbonate is the most and sodium chloride the least harmful of the three.

10. The alkali salts have the worst effect on the Medium black soil while their effect is the least on the Laterite which is an acidic soil.

11. The alkali salts with the quantities used in the experiments show a stimulating effect on the nitrogen recuperation power of the River silt soil.

12. The River silt which is a freshly deposited soil is easily stimulated by the addition of lime, phosphoric acid or organic matter and is also stimulated by the addition of small quantities of alkali salts in increasing its nitrogen recuperation power.

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PRELIMINARY WORK ON THE MANURING OF SUGARCANE IN NORTH BIHAR.

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INTRODUCTION.

Sugarcane is the most widely grown cash crop of North Bihar, and is yearly becoming of greater importance in the economy of the ryot; and for some years work on (*a*) the testing of new varieties for distribution, (*b*) better methods of cultivation and (*c*) manuring, has taken a leading place on the Departmental farms in the range. From (*a*) the Coimbatore varieties Co. 210 and Co. 213 have spread themselves over the range. From (*b*) the growing of the crop in lines, intercultivation through the hot weather and earthing during the monsoon with cheap bullock-drawn implements, have spread through the European factories and are gradually being adopted by the ryots. In (*c*) progress, though much slower, has now reached a definite stage.

It must be remembered that over the greater part of the tract, sugarcane is grown entirely without irrigation. The cane is planted shallow in February and early March, the land is beamed flat, and hoeings or intercultivations given at intervals through the hot weather to keep down weeds and conserve moisture till the monsoon. In certain areas where the soils are heavy and seem to dry out early, feeble irrigations are given in the hot weather, severely limited by the supply of water available and solely to keep the cane alive. Similarly supplies of farmyard manure are always inadequate and the cane gets generally a very small dressing. Where the land is a medium loam in really good condition yields of 600 to 800 maunds per acre are common but on most ryots' lands, owing to poor cultivation and inadequate manuring, the yields rarely exceed 300 maunds per acre.

Earlier manurial trials.

Manurial trials on sugarcane were started tentatively in the North Bihar Range at the Sepaya Farm in 1925-26. It had been the custom for years to prepare the land for cane by green manuring with *Sanai* and by adding heavy dressings of cattle manure ; also at first, small dressings of artificials were added to these preparatory applications for experimental purposes. The first trial in 1925-26 was to test the effect of extra nitrogen, and 80 lbs. 100 lbs. and 120 lbs. nitrogen per acre in the form of ammonium sulphate, was added to the basal dressing. The results (Table I) showed that the extra nitrogen had little effect and that what increase was obtained was not economic. But in the same year the effect of 80 lbs. P_2O_5 per acre added to the basal dressing, was tested against that of 80 lbs. nitrogen in ammonium sulphate ; as a result it was found that the plots given super gave 11 per cent. more cane than those given ammonium sulphate, and the difference was statistically significant (Table II). In a third trial in the same year where super to give 80 lbs. P_2O_5 was added to 80 lbs. nitrogen in ammonium sulphate, both on top of the basal dressing, the addition of the P_2O_5 increased the yield by a statistically significant 10 per cent. (Table III). In both cases the increases were only 70 odd maunds of cane, but that was because the land having been well prepared and manured, the yields of control plots were high. The important point remained that even on such good land, P_2O_5 still gave an appreciable and constant increase.

The writer took over the range in the cold weather of 1926-27 and found that that season had been almost entirely wasted for this purpose because in the manurial trials small dressings of artificials had been added as top dressings on the richest and most heavily-manured cane land and of course gave little or no effect. But from other trials on rabi crops it was further made clear that this soil did respond to applications of P_2O_5 in a marked degree ; and in one cane trial the substitution of 65 lbs. P_2O_5 for 40 lbs. nitrogen in a dressing of 80 lbs. nitrogen, gave a small but highly significant increase, though all the yields were very high (Table IV). It seemed clear that on this land phosphatic manures were likely to be more profitable than nitrogenous ones.

In 1927-28, therefore, only phosphatic manures were tested, no preliminary manures were given to the plots and sufficient replications and controls were included to give a high degree of significance. Unfortunately the writer, selecting a uniform plot, picked one also very rich, so that all the yields were very high and the effect of the manures was to a great extent masked. Even so (*vide* Table V) super to give 50 lbs. P_2O_5 per acre gave its usual 10 per cent. increase statistically significant, Guano at $3\frac{1}{2}$ maunds per acre, Ammophos to supply 38 lbs. nitrogen and 48 lbs. P_2O_5 gave only insignificant results.

Manurial trials on Sugarcane, Sepaya (Saran), 1925-26 and 1926-27.

Year, crop and place	Preparatory manuring	Manures tested	Number of replications and size of plots	Mean yield per plot maunds	Statistical treatment by student's short method. Ed.	Plots compared	Md./Ed.	Notes
			TABLE I.					
1925-26, Co. 213, Sepaya	Green manuring and farmyard manure	Ammonium sulphate (1) 80 lbs. nitrogen per acre	6	51·5	1·6	1 and 2	0·2	
		(2) 100 „	·094 acre	51·8	..	1 and 3	2·1	
		(3) 120 „	..	54·8	..	2 and 3	1·9	
			TABLE II.					
1925-26, Co. 210, Sepaya	Green manuring and farmyard manure	(1) Super 80 lbs. P_2O_5 per acre	6	53·4	1·7	1 and 2	3·2	80 lbs. P_2O_5 gave 11 per cent. more crop than 80 lbs. nitrogen.
		(2) Ammonium sulphate 80 lbs. nitrogen per acre	·072 acre	47·9	..	..	..	
			TABLE III.					
1925-26, Co. 210	Green manuring and farmyard manure	(1) Ammonium sulphate Nitrogen 80 lbs. per acre + Super P_2O_5 80 lbs. per acre	6 ·072 acre	56·8 ..	1·7 ..	1 and 2 ..	3·1 ..	The addition of 80 lbs. P_2O_5 to the 100 lbs. nitrogen increased the crop by 10 per cent.
		2. Ammonium sulphate Nitrogen 80 lbs. per acre	..	51·6	..	..	..	
			TABLE IV.					
1926-27, Co. 210, Sepaya	Green manuring and farmyard manure	1. Ammonium sulphate Nitrogen 40 lbs. per acre + Super P_2O_5 65 lbs. per acre	5 ·027 acre	31·5	·3	1 and 2	4·3	The substitution of 40 lbs. nitrogen by 65 lbs. P_2O_5 per acre increased the yields by 4 per cent. though the yields were very high.
		2. Ammonium sulphate Nitrogen 80 lbs. per acre	..	30·2	..	..	..	

Manurial Trials on Sugarcane Sepaya, Saran, 1927-28.

Year, crop and place	Manures tested in lbs. per acre			Number of replications and size of plots	Mean yield per plot maunds	Statistical treatment by student's short method			Notes
	Kind	Nitrogen	P_2O_5			Ed.	Plots compared	Md. / Ed.	
				TABLE V.					
1927-28, Co. 210, Sepaya	1. No manure			9	21·4	·58	1 and 3 with 2	2·1	
	2. Super	0	40	2 ch. × 9 ft.	22·6	..	..	..	Although the land was very rich Super gave a 10 per cent. increase, Guano gave an increase also but decidedly less while Ammophos gave no significant increase.
	3. No manure			= 3 acres / 110	19·9	..	3 and 4	2·4	
	4. Guano			..	21·3	..	2 and 4	2·24	
	5. No manure			..	20·7	..	..	..	
	6. Ammophos	38 lbs.	50	..	21·5	..	..	..	

Accurate Trials on Representative Land in Different Parts of North Bihar.

By 1928-29 we had realised that most of our land was far richer than that used for cane in the districts, and we must therefore put our trials on the poorest uniform land we could find on the farm, that only small dressings of nitrogen seemed likely to be effective while the important application was phosphate, but that the best amount to use and the best time to apply it were doubtful. Also we had by now standardised the method of trial, using plots, 2 chains long and 5 rows wide, of which only the three centre ones were to be manured, the two side rows of each plot being border ones. Manures applied at planting were put in the furrows under the sets of the three centre rows. Those applied at earthing were spread in the right quantities in the four centre inter-row spaces of the plot, mixed into the soil with a cultivator, and thrown up to the rows of cane by the earthing. There were at least 6 repetitions of the whole series of treatments and unmanured control plots were scattered at frequent and regular intervals.

At Sepaya two decidedly elaborate trials were laid down—

(i) on *diara* land inside the farm, selected as of medium fertility and thought to be fairly uniform, and not manured except in the trial ; and in this series plots

receiving farmyard manure at 270 maunds per acre ploughed in December for February planting, were included.

(ii) on high, light, poor land outside the farm, selected as being very poor but apparently uniform and healthy. The farmyard manure series had to be omitted from this series because the area of land available was insufficient.

The table below shows the arrangement of the plots, the dressings applied, the points it was hoped to bring out, and the mean yields per plot.

TABLE VI.

No.	Manures applied in lbs. per acre				Comparisons it was hoped to make	Mean yields per plot in seers. Average of 6 replications	
	At planting		At earthing			Co. 210 on *diara* farm land	Co. 213 on poor high land
	N	P_2O_5	N	P_2O_5			
1	Farmyard manure at 270 maunds per acre in December					951	..
2	No manure		..	..	Standard dressing of Farmyard manure *Vs.* No manures *Vs.* 40 lbs. nitrogen & 50 lbs. P_2O_5	800	367
3	20	50	20	0		906	531
4	20	25	20	25	Effect of different times of application of the phosphate	886	548
5	20	0	20	50		891	557
6	No manure		..	..	No manure *Vs.* 40 lbs. N and 50 lbs. P_2O_5 *Vs.* 40 lbs. nitrogen and 100 lbs. P_2O_5	849	366
7	20	50	20	50		901	660
8	0	50	40	50	Effect of different times of applying nitrogen	890	616
9	0	50	60	50	Effect of different quantities of nitrogen	836	646
10	No manure		..	..	....	757	376

These two trials, both during their growing period and from final results, gave much important information. On the richer heavier *diara* land all yields were high and differences relatively small, *usar* patches developed during the season and yields were irregular and the probable error relatively high. The farmyard manure gave 139 maunds per acre stripped cane more than the no-manure plots, and this difference was highly significant $\left(\frac{\text{Md}}{\text{Ed.}} = 5{\cdot}1\right)$. Both 40 lbs. nitrogen and 50 lbs. P_2O_5 and 40 lbs. nitrogen and 100 lbs. P_2O_5 gave approximately the same increase, 90 maunds per acre, over the no-manure plots $\left(\frac{\text{Md.}}{\text{Ed.}} = 3{\cdot}6\right)$ but the difference between the best yield from the 40·50 dressing and that from the farmyard manure was not significant. No significant differences could be detected on account of different times of applying the P_2O_5 or the nitrogen.

But on the poor, high, light land outside the farm very different results were observed. To begin with the effects of the manurial dressings compared with no manures were very obvious to the eye from August onwards and the greater benefit due to the heavier applications of phosphates was equally visible. On the unmanured plots the cane was even but poorly tillered, badly grown, yellow and unhealthy, heavily attacked by borer. The plots that received 40 lbs. nitrogen and 50 lbs. P_2O_5 were obviously better in every respect and those dressed with 40 lbs. nitrogen and 100 lbs. P_2O_5 were visibly better still. The final weighings confirmed these observations and gave further details. 40 lbs. nitrogen and 50 lbs. P_2O_5 gave a significant increase over no manure of 150 maunds per acre, $\left(\frac{\text{Md.}}{\text{Ed.}} = 8{\cdot}1\right)$. 40 lbs. nitrogen and 100 lbs. P_2O_5 gave an increase of 250 maunds per acre $\left(\frac{\text{Md.}}{\text{Ed.}} = 13{\cdot}6\right)$

The difference of 100 maunds between the results of these dressings was very significant $\left(\frac{\text{Md.}}{\text{Ed.}} = 4{\cdot}8\right)$. Applying part of the nitrogen at planting and the rest at earthing as contrasted with applying it all at earthing gave an increase of 40 maunds per acre, just significant.

But differing times of applications of the phosphate made no difference nor did an increase in the nitrogen applied (Tables VII & VIII).

At the Sewan Farm in the same season a much simpler trial was carried through on Co. 210 cane on land lightly manured with cow-dung in which 20 lbs. nitrogen and 50 lbs. P_2O_5 at planting was tested against no manure and 20 lbs. nitrogen and 50 lbs. P_2O_5 at planting with a further 20 lbs. of nitrogen at earthing. For plan and detailed results see Table IX. 20 lbs. nitrogen and 50 lbs. P_2O_5 at planting gave a just significant increase of 62 maunds per acre over no manure and the addition of a further 20 lbs. nitrogen at earthing raised this increase to 132 maunds per acre.

Manurial trials on Sugarcane 1928-29 (Saran District).

Nature of trial and crop	Manures applied in lbs. per acre				No. of replications and size of plots 6 replications	Mean yield per plot	Statistical treatment by student's short method			Notes
	At planting		At earthing				Ed.	Plots compared	Md./Ed.	
	N	P_2O_5	N	P_2O_5						
1928-29, Co. 210, Sewan						TABLE VII.				
1	No manure				..	17·9 mds.	·88	1 & 2	4·1	40 lbs. nitrogen and 50 lbs. P_2O_5 has given a very significant increase over no manure and a just significant one over 20 lbs. nitrogen and 50 lbs. P_2O_5.
2	20	50	20	..	Plots 2 chains ×9 feet.	21·5 ,,	..	2 & 4	2·2	
3	No manure				..	17·9 ,,	..	3 & 4	1·94	
4	20	50	..	..	..	19·6 ,,	..	..	..	
5	No manure				..	17·7 ,,	..	..	..	

Nature of trial and crop	Manures applied in lbs. per acre				No. of replications and size of plots 6 replications	Mean yield per plot	Statistical treatment by student's short method			Notes
	At planting		At earthing				Ed.	Plots compared	Md. / Ed.	
	N	P_2O_5	N	P_2O_5						
						TABLE VIII.				
Sepaya Co. 210 cane on diara land										
1	Farmyard manure at 270 mds. per acre in December				..	951 seers	29·57	1 & 2	5·158	All the manurial dressings have given very significant increase over the "no manure", but the difference between the different dressings are not significant. The relative richness of the land made the heavier dressings of no more avail than the light ones, and its irregularity of fertility militated against the detection of differences due to the different times of application of the phosphate.
2	No manure				6 replications plots 2 chains long by 3 rows = 9 feet wide with two border rows per plot not included.	800 ,,	29·57	2 & 3	3·621	
3	20	50	20	0		906 ,,	29·57	..	..	
4	20	25	20	25		886 ,,	29·57	2 & 4	2·938	
5	20	0	20	50		891 ,,	31·83	5 & 6	2·828	
6	No manure					849 ,,	31·83	6 & 7	3·142	
7	20	50	20	50		901 ,,	31·83	..	..	
8	0	50	40	50	..	891 ,,	31·83	6 & 8	2·797	
9	0	50	60	50	..	836 ,,	..	..	..	
10	No manure				..	757 ,,	..	..	..	
						TABLE IX.				
Sepaya Co. 213 cane on poor high land										
1	No manure				..	367 seers	20·2	..	..	In this trial the land was poorer but more uniform and the differences due to the manures were very evident to the eye from August onwards. The differences due to all the manurial dressings were very large and very significant, while though dressings of 40 lbs. nitrogen and 50 lbs. P_2O_5 gave increases of 150 mds. of cane per acre the addition of a further 5 lbs. per acre increased this difference to 250 mds. The time of application of phosphate, *i.e.*, whether applied early or late had no effect, but applying part of the nitrogen early increased the yield by 40 mds. per acre and chances are just over 30: 1 that this is real.
2	20	50	20	0	..	531 ,,	..	1 & 2	8·1	
3	20	25	20	25	..	548 ,,	..	1 & 3	9·0	
4	20	0	20	50	..	557 ,,	21·58	4 & 5	8·389	
5	No manure				..	366 ,,	21·58	4 & 6	4·773	
6	20	50	20	50	..	660 ,,	21·58	5 & 6	13·62	
7	0	50	40	50	..	616 ,,	20·86	6 & 8	2·109	
8	0	50	60	50	..	646 ,,	..	..	..	

From the results of this season's trials it seemed clear that on the kind of land on which cane is generally grown by cultivators in North Bihar a dressing

of artificial manure containing between 40 lbs. nitrogen and 50 lbs. P_2O_5 and 40 lbs. nitrogen and 100 lbs. P_2O_5 was likely to be very profitable on cane.

The question of farmyard manure was postponed for the present as very inadequate dressings are available for use on cane by cultivators, and the question of time of application of the phosphate was further investigated at Sepaya. But the other farms in the range were utilised for a range manurial trial on sugarcane on the following plan, the trial being in every case on land not manured in its preparation for the cane crop.

Manures applied in lbs. per acre.

	At planting		At earthing		Total	
	N	P_2O5	N	P_2O_5	N	P_2O_5
1	..	..	No manure	..	..	..
2	20	25	20	25	40	50
3	20	37·5	20	37·5	40	75
4	..	..	No manure	..	..	..
5	20	50	20	50	40	100
6	20	50	40	50	60	100

Plots were repeated in the same order at least 6 times and finished with an extra no-manure plot. The trials were all carried through according to the technique standardised in 1927-28, and as the results came in, they were treated statistically by student's short method and the results have been published in the annual reports of the farms concerned.

There are so far seven results of this trial available and except for the one already discussed as on poor high land at Sepaya all show much the same features.

1. In all the trials the dressing of 40 lbs. nitrogen and 50 lbs. P_2O_5 per acre, part at planting and part at earthing, has given a statistically significant increase of crop ranging from 66 maunds per acre on poor heavy land at Sewan in 1930-31 when, on account of drought, the stand of cane was so bad as to yield only 240 maunds per acre on the unmanured plots, to 253 maunds per acre at Darbhanga in the same year.

2. In no trial except the Sepaya one of 1928-29 has either 40 lbs. nitrogen and 75 lbs. P_2O_5 or 40 lbs. nitrogen and 100 lbs. P_2O_5 given an appreciable or significant increase over the 40 : 50 dressing.

3. In only one case, that of Darbhanga, 1929-30, has the dressing of 60 lbs. nitrogen and 100 lbs. P_2O_5 given a significantly better yield than the 40 lbs. nitrogen and 100 lbs. P_2O_5.

North Bihar Range.

Year	Place	Cane	Mean yields in Mds. per plot (132′ × 9′) from each treatment						No. of replications	Ed.	Remarks
			Manures applied in lbs. per acre								
			No Manure	N 40 P_2O_5 50	N 40 P_2O_5 75	No Manure	N 40 P_2O_5 100	N 60 P_2O_5 100			
			TABLE X.								
1929-30	Sewan .	213	16·4	19·4	19·9	16·8	18·8	19·1	5	·63	40 : 50 gives significant increase $\frac{Md.}{Ed.}$ = 4·7.
			TABLE XI.								
Do. .	Darbhanga	213	14·14	20·42	20·42	14·69	19·99	22·63	7	·70	40 : 50 gives significant increase $\frac{Md.}{Ed.}$ = 9·0. 60 : 100 significantly better than 40 : 100 $\frac{Md.}{Ed.}$ = 3·8.
			TABLE XII.								
Do. .	Purnea .	213	18·83	21·19	22·13	20·26	20·22	21·79	6	1·03	40 : 50 gives significant increase $\frac{Md.}{Ed.}$ = 2·3.
			TABLE XIII.								
1930-31	Sepaya .	213	8·9	12·8	..	..	13·1	..	6	·6	40 : 50 gives significant increase $\frac{Md.}{Ed.}$ = 6·3.
Do. .	Do. .	213	..	..	..	10·8	13·0	14·1	6	·8	60 : 100 gives significant increase $\frac{Md.}{Ed.}$ = 4·1. This trial was in 2 series.
			TABLE XIV.								
Do. .	Sewan .	213	9·1	10·9	10·1	8·8	10·9	11·4	5	·5	Owing to lack of moisture in hot weather on this heavy land stands very irregular 40 : 50 gave significant increase $\frac{Md.}{Ed.}$ = 3.
			TABLE XV.								
Do. .	Darbhanga	213	9·0	15·9	16·4	8·0	17·8	19·6	5	2·9	40 : 50 gave significant increase $\frac{Md.}{Ed.}$ = 2·8.
			TABLE XVI.								
Do. .	Byreah Champaran	213	17·6	22·9	24·6	17·3	24·0	24·0	8	1·13	40 : 50 gave significant increase $\frac{Md.}{Ed.}$ = 4·7.

Definite results.

In all ten trials, ranging over North Bihar through the three seasons 1928-29 to 1930-31, the dressing of 40 lbs. nitrogen and 50 lbs. P_2O_5 has given a substantial and significant increase of cane crop in every case ; but in only 2 cases have any of the other dressings tried improved on this. From these ten trials, I have extracted the figures giving the yields of the no manure plots and of those dressed with 40 lbs. nitrogen and 50 lbs. P_2O_5 per acre, which were in every case alongside one another, and combined them in Table XVII with details of the location of the trial, the kind of cane used, the kind of land and the season. The increases in crop are shown both in maunds per acre and as percentages of the unmanured yields, and the degree of significance has been shown by the ratio $\frac{\text{Mean difference}}{\text{Error of difference}}$, in which a ratio of 2·1 means a 30:1 chance that the difference is due to the treatment.

Table XVII.

Showing the effects of a dressing of 40 lbs. nitrogen and 50 lbs. P_2O_5 per acre on sugarcane in North Bihar from 1928 to 1931.

Year	Place	Kind of soil	Season	Size and shape of plots	No. of repetitions	Yields per plot in mds.		Increase per acre	Percentage increase	Ed.	Md./Ed.
						No manure	Manured with 40 lbs. N. 50 lbs. P_2O_5 per acre				
1. 1928-29	Sepaya Co. 210	Diara rich loam.	Fair .	132′ × 9′	6	20·0	22·6	95·3 mds.	13·2	·57	4·6
2. do. .	Do. Co. 213	Poor light high land.	Do. .	Do. .	6	9·2	13·3	150 ,,	45	·45	9·1
3. do. .	Sewan Co. 210	Heavy fairly rich.	Good .	Do. .	6	17·9	21·5	132 ,,	20	·75	4·8
4. 1929-30	Do. Co. 213	Heavy poor .	Fairly good.	Do. .	5	16·4	19·4	110 ,,	18	·51	5·9
5. do. .	Darbhanga 213	Medium loam poor.	Good .	Do. .	7	14·1	20·4	231 ,,	44	·43	14·7
6. do. .	Purnea Co. 213	Medium loam very rich.	Do. .	Do. .	6	18·8	21·2	88 ,,	13	·73	3·3
7. 1930-31	Sepaya Co. 213	Light high land rather *usar*.	Very bad short monsoon.	Do. .	6	8·9	12·8	143 ,,	44	·59	6·6
8. do. .	Sewan Co. 213	Heavy very poor.	Very bad stand of cane Very poor.	Do. .	5	9·1	10·9	66 ,,	20	·44	4·1
9. do. .	Darbhanga 213.	Ditto .	Fairly good.	Do. .	5	9·0	15·9	253 ,,	77	1·58	4·4
10. do. .	Byreah . .	Medium loam rich.	Good .	Do. .	8	17·6	22·9	195 ,,	30	·59	9·0
								1,463			
								Mean 146 maunds per acre.			

The small difference at Sewan in 1930-31 has already been explained by the very irregular stand through all the plots due to lack of moisture in the hot weather on heavy soil. At Purnea the land was very rich and the soil does differ in important respects from that of the western districts of the range. Darbhanga shows a high increase in both years the trial was conducted there, while at Byreah in Champaran district, in the only trial so far completed the increase is also very high.

The mean of the 10 increases is 146 maunds per acre, 5 are above this and 5 below of which 2 are definitely abnormal. We are justified in concluding that on average cultivator's land, a dressing of 40 lbs. nitrogen and 50 lbs. phosphoric acid applied in 2 doses to the cane, half at planting and half at earthing will give an increase of crop of about 146 maunds per acre, most probably more.

Recommendations.

In all our trials we have used the various artificial manures entirely according to convenience in obtaining them, some times mixtures of ammonium sulphate and superphosphate, sometimes ammophos—16 per cent., nitrogen 20 per cent., P_2O_5—diammonphos—20 per cent., N 50 per cent., P_2O_5—or leunophos —20 per cent., N 20 per cent., P_2O_5. No differences from the use of the different ones have so far appeared. For convenience of working in that only one manure need be purchased and handled in the field, we can at this stage safely recommend for cane either 3 maunds per acre of ammophos (16:20) or $3\frac{1}{2}$ maunds per acre Niciphos No. II, whichever is cheaper or more conveniently obtainable. Half the amount should be applied at planting and half at earthing.

The next stage.

Large numbers of cultivators use cattle-dung in varying quantities on their cane. Planters practise green manuring on a considerable scale. There are now-a-days available large quantities of very cheap oil-cakes. There is no doubt as to the value of the first two as adding humus as well as plant food to the soil. Whether the third is of any serious value except as a plant food is doubtful. But all three add to the soil less P_2O_5 than nitrogen, whereas our work seems to show the reverse to be required. Our future work therefore is being directed to trying to discover what supplement in the way of extra P_2O_5 is required with those three manures and whether additional nitrogen will also be profitable.

INHERITANCE OF AWN COLOUR IN WHEAT.

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INTRODUCTION.

In wheats the awn colours are black, red or white. The intensity of colour varies in each group. Black awns may be deep-black or merely sooty in appearance. The red-awned group may embrace various shades of brown or red, and the white-awned group may include yellow or yellowish-white.

The three major awn colours are found wherever wheat is grown. Percival [1921] finds black awns commonly occurring in *T. turgidum* and in *T. durum*, but rare in *T. vulgare*.

The colour in awns is greatly affected by climatic conditions. Certain black-awned wheats develop pigment in hot seasons only; damp and cool conditions suppress colour formation. In some wheats, however, black awn colour remains constant under varying climatic conditions, Percival [1921].

PREVIOUS INVESTIGATIONS.

Very little work has been reported on the heredity of awn colour in wheat. This is probably due to the fact that complications are introduced by climatic conditions.

The Howards [1913] made a cross between a black and a white-awned wheat and obtained in F_2 466 black and 135 white-awned plants. The numbers show a mono-hybrid inheritance.

Percival [1921] opines that awn colours follow the same type of inheritance as that of glumes. Both black and red being dominant to white, and black dominant to red.

Material and Methods.*

The investigation reported in this paper was carried at the Wheat Breeding Station, Kirkee, near Poona. Both the parents used in crosses are pure strains, maintained such for a number of years. These were isolated from wheats obtained from the Nasik district.

The female parent Kala-khapli 568 (*T. dicoccum*) has black awns and is very resistant to the rust, *Puccinia graminis tritici*.

The red-awned male parent Bansi 103 (*T. durum*) is a late, high-yielding selection, but extremely susceptible to the black stem rust. To obtain Bansi-like rust resistant strains crosses between these two strains were made in the season of 1925-26. Incidentally other characters were studied, awn colour being one of them.

The F_1 plants were grown in pots during the 1926-27 season, and three successful crosses were obtained. The black awn colour was found to be dominant to red.

The three crosses were designated H6, H7 and H8. The first yielded 74 grains and the other two 72 grains each. All of these were planted four inches apart in twentyfour-foot rows in the season of 1927-28. Due to the attack of *Fusarium* and *Rhizoctonia*, many plants died in the seedling stage and in all only 149 plants were obtained in F_2.

The F_3 generations were obtained in 1928-29. From each F_2 plant 146 seeds were planted four inches apart in rows.

The awn colours were noted in the field and again in the laboratory. Both the black and red awns have various shades, but variations when unaffected by atmospheric conditions are distinct enough to be classed as either black or red. The complete linkage of pubescent glumes and black awns, however, facilitated separation of black awns from red. The white awns, which appeard in F_2 were distinct and were easy to classify.

Goodness of Fit has been worked out according to Fisher [1928]. In his table Fisher has given values of X^2 corresponding to specially selected values of P. "If P is between ·1 and ·9 there is no reason to suspect the hypothesis tested." However, if P is below ·05 then the higher value of X^2 indicates a significant departure from hypothesis.

Results.

F_1 Generation.

The F_1 generation of the cross ♀ Kala-khapli 568 × ♂ Bansi 103 was like the female parent; black awn colour being dominant to red.

*The work was carried under the supervision of the following successive Crop Botanists to the Government of Bombay; Mr. R. K, Bhide, until 1927, Mr. S. G. Bhalerao, B.Ag., from 1927 to 1929; and Mr. R. K. Kulkarni, B.Ag., 1929-30. The present senior author has been in charge of the work since April 1930.

F_2 Generation.

In F_2 generation, besides the parental black and red awn colours, some plants were found to have white awns. The distribution of F_2 population was as follows:—

TABLE I.

Segregation of Awn colour in F_2.

Awn colour	Observed	Calculated 12 : 3 : 1	$\frac{(O-C)^2}{C}$
Black	107	111·7500	0·2019
Red	29	27·9375	0·0404
White	13	9·3125	1·4601
Total	149	149·0000	X^2 1·7024

P between ·30 and ·50.

On the basis of 12 : 3 : 1 ratio the observed data closely fit the expected ones.

F_3 Generation.

Behaviour of F_2 black-awned plants:—The behaviour of F_2 in F_3 generation was quite diverse. Out of the 32 black-awned plants ten bred true to character. Six of the plants segregated into black and red awns as follows:—

TABLE II.

F_2 Black-awned plants splitting into black and red-awned plants in F_3.

Culture No.	Observed		Calculated. 3 : 1		Total.	D. / *P. E.
	Black	Red	Black	Red		
6—4	53	21	55·50	18·50	74	$\frac{2·59}{2·51}=0·99$
6—61	75	24	74·25	24·75	99	$\frac{0·75}{2·90}=6·26$
6—62	64	23	65·25	21·75	87	$\frac{1·25}{2·72}=0·46$
6—65	60	18	58·50	19·50	78	$\frac{1·50}{2·57}=0·58$
6—70	24	4	21·00	7·00	28	$\frac{3·00}{1·54}=1·94$
8—64	59	27	64·50	21·50	86	$\frac{5·50}{2·70}=2·03$
Grand total	335	117	339·00	113·00	452	$\frac{4·00}{6·20}=0·64$

* The formula, $·6745\sqrt{p.\ q.\ n.}$ was used, where p is the percentage of individuals in one of the two classes, q is 1·0—p and n the total number of observations.

In almost all the cases the observed numbers are surprisingly close to expected ones. The last two cultures show somewhat large deviations. The odds against the occurrence of deviations as great or greater than these are 4 : 1 and 4·64 : 1 respectively. The grand totals of black and red awns deviate only by four from the calculated frequencies. The deviation is only ·61 times the probable error. Since black is throwing red coloured awns it must be dominant to red.

Ten of the F_2 black-awned plants segregated into black and white-awned plants as shown in the following table.

TABLE III.

F_2 Black-awned plants splitting into black and white-awned plants in F_3.

Culture No.	Observed		Calculated 3 : 1		Total	$\frac{D.}{P.E.}$
	Black	White	Black	White		
6—5	63	24	65·25	21·75	87	$\frac{2·25}{2·72}=0·83$
6—7	44	25	51·75	17·25	69	$\frac{7·75}{2·42}=3·10$
6—11	77	25	76·50	25·50	102	$\frac{0·50}{2·95}=0·17$
6—18	73	21	70·50	23·50	94	$\frac{2·50}{2·83}=0·88$
6—22	50	12	46·50	15·50	62	$\frac{3·50}{2·29}=1·52$
6—41	68	23	68·25	22·75	91	$\frac{1·75}{2·78}=0·63$
6—43	82	27	81·75	27·25	109	$\frac{0·25}{3·04}=0·08$
6—71	18	6	18·00	6·00	24	0 0
6—73	12	2	10·50	3·50	14	$\frac{1·50}{1·09}=1·37$
8—7	59	15	55·50	18·50	74	$\frac{3·50}{2·51}=1·39$
Grand total	546	180	544·50	181·50	726	$\frac{1·50}{7·86}=0·19$

With the conspicuous exception of culture 6-7, all the others give very close fits to calculated numbers. The deviation is 7·75, and 3·19 times the probable error, indicating the probable occurrence of a deviation as great or greater in only three out of a hundred trials. This is certainly a very poor fit. But examining the behaviour of other cultures it becomes at once apparent that some mechanical agent must be a disturbing factor in culture 6-7. It will be noted that the odd behaviour of culture 6-7 is mainly due to the shortage of black-awned plants. These may have died due to the attack of *Fusarium* and *Rhizoctonia* in the seedling stage.

The grand total of observed black and white-awned plants gives almost a perfect fit to expected numbers.

The remaining six black-awned plants gave progenies like that of the F_1 plants. The distribution of awn colour for each culture was as follows :—

TABLE IV.

F_2 Black-awned plants segregating into black, red and white-awned plants in F_3.

Culture No.	Observed.			Calculated. 12 : 3 : 1			Total	X^2	P Between
	Black	Red	White	Black	Red	White			
6—21	53	9	5	50·25	12·5625	4·1875	67	1·3180	·30 & ·50
6—24	18	8	3	21·75	5·4375	1·8125	29	2·6321	·20 & ·30
6—37	81	13	7	75·75	18·9375	6·3125	101	2·3008	·30 & ·50
6—39	74	11	5	67·50	16·8750	5·6250	90	2·7407	·20 & ·30
6—56	81	18	6	78·75	19·6875	6·5625	105	0·2571	·80 & ·90
6—66	73	9	5	65·25	16·3125	5·4375	87	4·2337	·10 & ·20
								ΣX^2 13·4824	·30 & ·50
Grand Total	380	68	31	359	90	30	479	6·6395	·02 & ·05

The value of P of individual cultures range between ·10 to ·90, indicating that the departures from expectation have no real significance. However, the X^2 value, 6·6395, of the grand total, gives a P below ·05, pointing to a probable discrepancy. This seems to be mainly due to the behaviour of culture 6—66 which has a large defficiency of red-awned plants.

However, when the X^2s are summed, the total, 13·4824, gives a value of P between ·30 and ·50 for 12 degrees of freedom, showing that all the cultures behave essentially the same.

Behaviour of F_2 red-awned plants in F_3.

Out of the ten red-awned plants four gave only red-awned progeny in F_3. The rest of the plants segregated into red and white-awned plants as shown in Table V.

Table V.

F_2 Red-awned plants segregating into red and white-awned plants in F_3.

Culture No.	Observed		Calculated 3 : 1		Total	$\frac{D.}{P.E.}$
	Red	White	Red	White		
6-15	50	25	56·25	18·75	75	$\frac{6·25}{2·52} = 2·48$
6-30	34	14	36·00	12·00	48	$\frac{2·00}{2·02} = 0·99$
6-31	52	21	54·75	18·25	73	$\frac{2·75}{2·49} = 1·10$
6-46	61	18	59·25	19·75	79	$\frac{1·75}{2·59} = 0·67$
6-47	70	27	72·75	24·25	97	$\frac{2·75}{2·87} = 0·96$
7-35	12	4	12·00	4·00	16	.. ..
Grand Total	279	109	291·00	97·00	388	$\frac{12·00}{5·75}$

All the cultures show very close approximations to expectation, except the first one. The odds against the occurrence as great or greater than the deviation of 6-15 are 9·98 : 1. The grand totals of red and white-awned plants give a deviation of 12 with a probable error of 5·75. The odds against the occurrence as great or greater than the observed one are 5·38 : 1.

Behaviour of F_2 white-awned plants.

Only four F_2 white-awned plants were grown in F_3. All of these bred true. In subsequent generations white-awned plants were observed to breed true, indicating their recessive nature.

Genic Interpretation.

It is evident from the foregoing data that both black and red awn colours are dominant to white condition, and segregate in monogenic proportions. The black awn colour is also dominant to red, showing an epistatic behaviour. Further more, there are some F_2 black-awned plants which behave like the F_1, indicating identical genic constitution.

The white awns, which first appeared in the F_2 progeny, bred constant throughout. They are, therefore, recessive in constitution.

The genes for black and red awn colours are designated as B and R respectively. As both the parents are derived from pure lines, they should have homozygous constitution. The gene R can express itself only in the absence of the epistatic gene B. The red-awned Bansi 103, therefore must have bbRR genotype. The other parent Kala-khapli 568, must be carrying opposite allelomorphs of Bansi, as the cross between the two presents a double heterozygous behaviour in F_2. Moreover, it has been found that the gene R simultaneously causes red colouration of glumes and awns, while the action of gene B is confined to awns only. The Khapli parent has white glumes indicating the presence of the recessive allelomorphs of gene R. The genotype of Khapli would, therefore, be BBrr.

The F_1 will be hybrid for both characters and upon self-fertilization would yield the following genotypes in F_2, whose F_3 behaviour is also indicated.

Awn colour	F_2 Genotypes	Behaviour in F_3
12 Black	1 B B R R	Breeds true.
	2 B B R r	Breeds true.
	2 B b R R	3 Black : 1 red.
	4 B b R r	12 Black : 3 red : 1 white.
	1 B B r r	Breeds true.
	2 B b r r	3 Black : 1 white.
3 Red	1 b b R R	Breeds true.
	2 b b R r	3 Red : 1 white.
1 White	1 b b r r	Breeds constant.

The presence of gene B either in a single or double dose, causes black awn colour. The first six genotypes, give black-awned condition. Of these, three breed true in F_3; one each segregates into 3 black : 1 red, and 3 black : 1 white. The

double heterozygotes split in all the three colours in the proportion of 12 black : 3 red : 1 white.

There are only two genotypes, b b R R and b b R r which produce red awns ; the latter breaks up in F_3 giving 3 red to 1 white.

The white, being a double recessive, breeds constant.

It will be seen from the data presented that the theoretical behaviour in F_2 and F_3 generations of the Kala-Khapli and Bansi cross has been entirely realized.

Summary.

1. Data are presented which show that the black awn colour of Kala-Khapli 568 (*T. dicoccum*) and the red awn colour of Bansi 103 (*T. durum*) are caused by two separate genes.

2. The gene B produces black colour of awns and is epistatic to the gene R.

3. The gene R causes red awns.

4. The modification of the ordinary dihybrid ratio to 12 : 3 : 1 is caused by the epistatic behaviour of the gene B.

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CORRELATION BETWEEN FROST AND THE PRECEDING METEOROLOGICAL CONDITIONS.

BY

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(With 4 figures.)

[*Summary* : This paper is the first of a series on correlation between frost and the preceding local meteorological conditions in Northern India. Lahore 16 hours (local time) observation for the period 1915-29 have been analysed statistically in the paper, and equations are developed between the minimum temperature of the night and the dew-point, wet bulb and dry bulb temperatures at 16 hours in the preceding afternoon. The physical significance of these statistical equations is discussed. The observed and the calculated values of the minimum temperature agree closely in over 93 per cent. cases ; the discrepancies in the remaining 6 or 7 per cent. cases are not large and the causes producing them are explained. Most of the occasions on which the discrepancies are liable to occur can be foreseen and allowed for by a forecaster having the facilities of the Indian synoptic chart.

Pressure distributions most favourable for the occurrence of frost are discussed. On account of the importance of minimum temperature forecasts to agriculture, the need of regular afternoon observations of air temperature and humidity under standard conditions of exposure at all agricultural centres is stressed.]

1. Introduction.

Temperature is one of the most important elements in determining the growth of plants, agricultural crops and fruits. Very high and very low temperatures affect crops in various ways, principally by preventing germination, checking growth, killing all or part of the vegetative parts, injuring the blossoms or damaging the maturing products. Most plants make growth only during the portion of the year, when the temperature remains within certain limits, maturing, dying or becoming dormant when the temperature exceeds these limits. It is believed [Smith 1920], that 6°C or 42°·8 F marks the temperature below which most field and garden crops and plants will make little, if any, development ; most of the tender varieties of these are either killed or seriously damaged if the temperature falls below the freezing point (32°F) for any considerable time.

As a result of nocturnal radiation, the minimum temperature of the night generally occurs in the early morning shortly before sunrise. The problem of forecasting frost in India, therefore, is closely connected with the problem of forecasting the night minimum temperature. This paper is the first of a series to determine the correlation between the night minimum temperature at a station and the local meteorological conditions in the preceding afternoon.

2. An examination of the available meteorological data for the plains of India shows that the temperature of the air in the Stevenson screen (height 4′ above ground) rarely falls to or below the freezing point outside the region comprising Kashmir, the Northwest Frontier Province, Baluchistan, the Punjab, Rajputana, north Sind, Central India, the west Central Provinces, the United Provinces and the submontane districts of Bihar, Bengal and Assam. Regular afternoon meteorological observations were introduced at the 2nd and 3rd class observatories of the India Meteorological Department in northern India about the end of 1929. The records at these observatories are therefore not sufficiently long for the purposes of a statistical study. There are a few first class observatories, namely, Quetta, Peshawar, Srinagar, Agra, Jaipur and Lahore in the above mentioned region at some of which afternoon records for a sufficiently long period are available. The afternoon observations recorded at Lahore at 16 hours (local time) during the period 1920-29 are discussed here ; those for the other stations will be taken up separately.

Since frost occurs on clear nights, when radiation from the ground is strong ; only data for clear nights were considered. A night was taken as clear when the amount of cloud was zero (on the scale 0-10) at the time of the preceding 16 hours routine observations, and 8 hours routine observations on the succeeding morning. During the period under examination, there were 81 such nights available in December, 63 in January and 62 in February. As a result of preliminary statistical examination, it was found that the data for December and January could be combined ; these months are therefore considered together in section 4. To increase the number of observations for February, data for another five years, 1915-19, were included for this month alone, thereby raising the number of observations for this month to one hundred.

Monthly Frequency of Frost.

3. Frost occurs in northern India during the period November-March, but at stations like Srinagar, it may also occur in September and May. The percentage frequency and the mean number of days of frost per month (*i.e.*, when the minimum temperature fell below 32°F) at Lahore at 4 ft. above ground and at the surface for each month of this period are given in Table I. Similar information in respect of Srinagar, Peshawar, Rawalpindi and Dehra-Dun is also included in the table,

for comparison. Of the five stations given in the table, grass minimum temperatures are available for Lahore and Srinagar only.

TABLE I.

Percentage frequency and the mean number of days of frost at Lahore, Srinagar, Peshawar, Rawalpindi and Dehra-Dun, in each month of the period September-May at 4 ft. above ground and at the surface (where available).

Station	Height A. S. L.	September	October	November	December	January	February	March	April	May	Total number of days of frost	Period of Record
					4 ft. above ground.							
Lahore . .	ft. 702	..	..	..	*36*	*36*	28	..	..	..	14	1901-29
					(0·2)	(0·2)	(0·1)					
Srinagar . .	5201	..	0·9	19	*29*	27	21	3	0·1	..	1719	1901-20
			(0·5)	(16·5)	(24·7)	(23·5)	(18·1)	(2·7)	(0·1)			
Peshawar. .	1164	..	..	..	*48*	38	14	..	..	..	81	1901-20
					(1·9)	(1·5)	(0·5)					
Rawalpindi .	1674	..	..	1	43	*44*	12	..	..	..	115	1901-20
				(0·1)	(2·5)	(2·7)	(0·7)					
Dehra-Dun .	2239	..	..	..	..	40	*60*	..	..	..	5	1901-20
						(0·1)	(0·1)					
					At the Surface							
Lahore . .	702	..	..	12	34	*33*	15	1	..	..	819	1913-29
				(5·6)	(16·5)	(18·0)	(7·5)	(0·5)				
Srinagar . .	5201	1	10	18	18	*19*	17	12	4	1	2505	1913-28
		(1·3)	(15·6)	(28·3)	(28·7)	(30·1)	(25·9)	(19·1)	(6·7)	(1·0)		

NOTE.—Figures within brackets denote the mean number of days of frost per month.

Table I shows, as might be expected, that frost is most frequent in December and January, the coolest months of the year. At Lahore, Rawalpindi, Peshawar and Dehra-Dun, it occurs almost entirely during the period December-February. Freezing temperatures are less frequent at 4 ft. above ground than at the surface on account of the strong inversions of temperature which prevail in the surface layers of the atmosphere in the dry season from evening to early morning. For example in the cool season at Lahore, the minimum temperature* of the air recorded in the Stenvenson screen (*i.e.*, 4 ft. above ground) may be higher than the grass minimum temperature (bulb $\frac{1}{2}''$ above ground) by about 8 to 10°F. The magnitude of this difference in temperature varies with the locality depending upon the exposure of the instruments, the nature of the ground surface and the composition of the atmosphere with regard to water vapour, carbon dioxide, and suspensions.

* Memoirs, Ind. Met. Dept. Vol. XII, page 45.

4. Relation between the minimum temperature (N) on a clear night and the dew-point (P), dry bulb (D) and wet bulb (W), temperatures of the air at 16·00 hrs. (local time) in the preceding afternoon.

Dot charts were prepared separately for the period December-January and February showing the relation between :—

(*a*) the depression of the dew-point below the dry bulb temperature at 16·00 hrs. local time (*i.e.*, D—P) and the difference between the minimum temperature of the night and the dew-point at 16 hrs. in the preceding afternoon (*i.e.*, P—N), and

(*b*) the dew-point of the air at 16 hrs. (local time) and the difference between this dew-point and the minimum temperature of the following night (*i.e.*, P—N).

The dot charts are reproduced in Figs. 1 to 4 below.

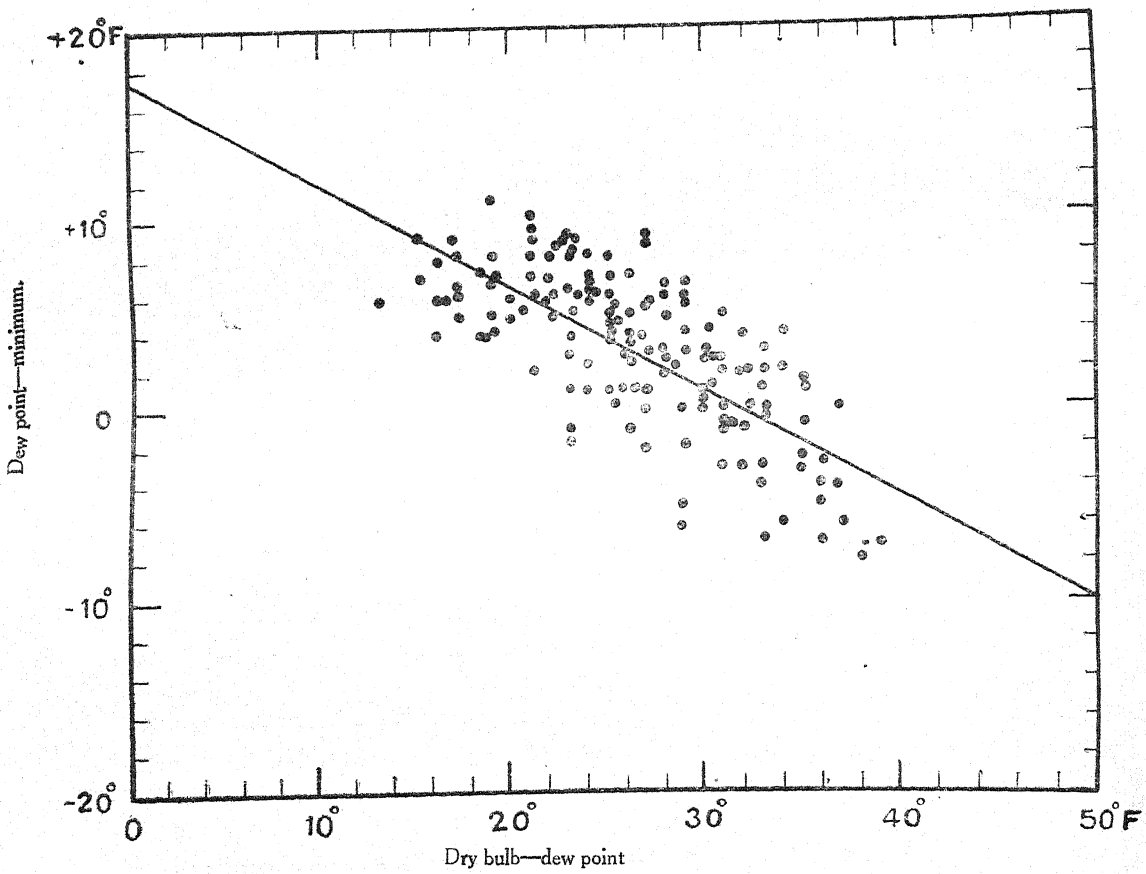

Fig. 1. Dot chart showing the relation between the dry bulb temperature minus the dew point at the evening observation (16 hrs. local time) and dew point minus minimum temperature at Lahore in Dec. & Jan. (1920—29).

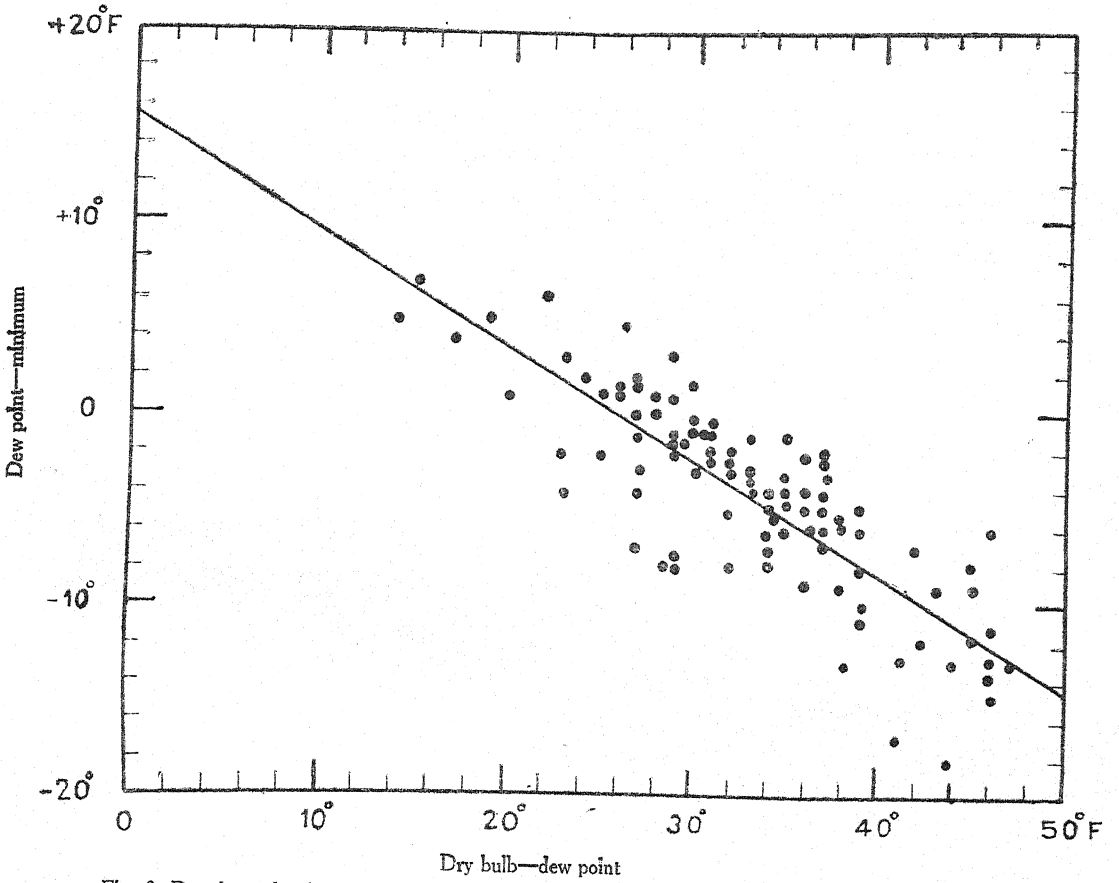

Fig. 2. Dot chart showing the relation between the dry bulb temperature minus dew point at the evening observation (16 hrs. local time) and dew point minus the minimum temperature at Lahore in February (1915—29).

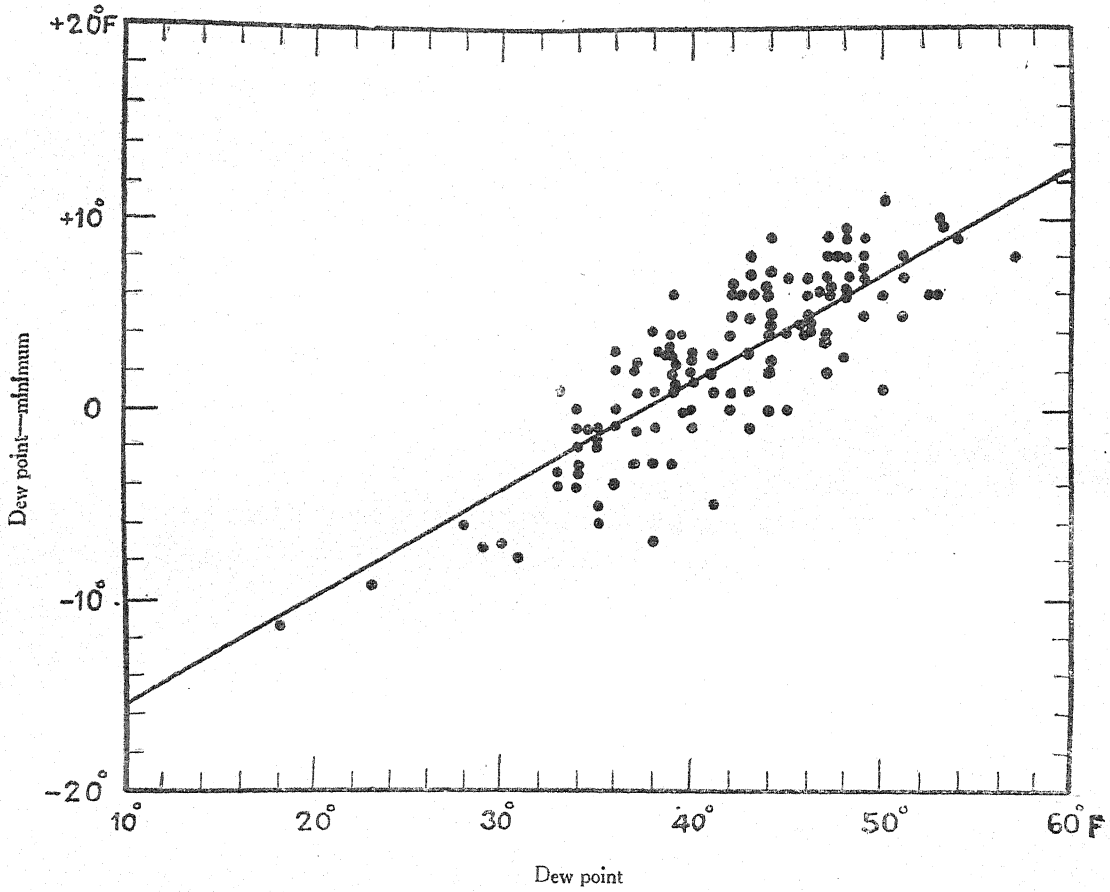

Fig. 3. Dot chart showing the relation between the evening dew point (16 hrs. local time) and dew point minus minimum temperature at Lahore in Dec. & Jan. (1920—29).

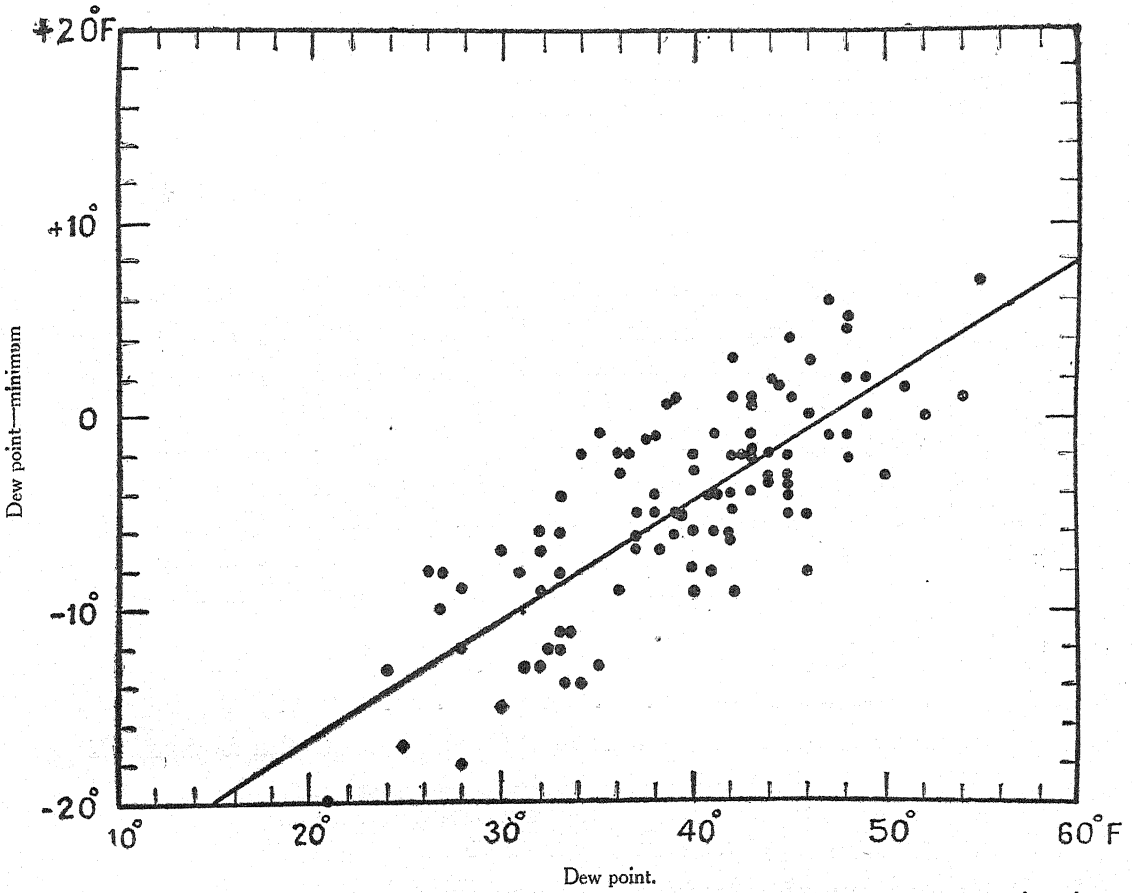

Fig. 4. Dot chart showing the relation between the evening dew point (16 hrs. local time) and dew point minus minimum temparature at Lahore in February (1915—29).

The charts show that the relation between the variables under reference is practically linear in each case. The continuous lines on the charts are the lines of best fit calculated by the method of least squares. The corresponding normal equations for the lines are :—

(1) December-January (1920-29); (dew-point —munimum) and (dry bulb —minimum), Fig. 1.

$$(P—N)=17{\cdot}3—0{\cdot}544\ (D—N) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

The scatter of the observed values of (P—N) about the line of best fit can be seen from the figure. Since P & D are known from the afternoon observations, the

value of N can be readily calculated from the above equation. The standard error of the estimate of N from this equation, *i.e.*

$$\sqrt{\frac{\Sigma(\text{observed value of N}-\text{calculated value of N})^2}{\text{total number of observations}}}$$

comes to 3·2°F.

(2) February (1915-29); (dew point —minimum) and (dry bulb —minimum), fig. 2.

$$(P-N)=15{\cdot}5-0{\cdot}604\,(D-N) \quad . \quad . \quad .

coefficients were worked out separately for February and the period December-January. The values of the coefficients together with their respective standard errors are given in Table II.

TABLE II.

Correlation Coefficients between the Minimum Temperature (N) of the night and the dew-point (P), dry-bulb (D) and wet-bulb (W) temperatures of the air recorded at 16 hrs. (local time) in the preceding afternoon at Lahore.

Elements correlated	Correlation Coefficient (r)	$\pm \frac{1-r^2}{\sqrt{n}}$	Number of Observations	Remarks
	December-January (1920-29)			
1. N and P . . .	+·72	·04	144	
2. N and D	+·43	·07	,,	
3. N and W . . .	+·72	·04	,,	
4. N and W and D . .	+·73	..	,,	Multiple correlation.
5. N and P and D . .	+·73	..	,,	Do.
6. D and P	+·46	·06	,,	
7. D and W . . .	+·70	·04	,,	
	February (1915-29)			
1. N and P	+·63	·06	100	
2. N and D . . .	+·71	·05	,,	
3. N and W . . .	+·80	·03	,,	
4. N and W and D . .	+·81	..	,,	Multiple correlation.
5. N and P and D . .	+·81	..	,,	Do.
6. D and P	+·38	·09	,,	
7. D and W. . . .	+·88	·02	,,	

r = Correlation coefficient, n = Number of observations.

The significance of each of the four multiple correlation coefficients was tested by analysing the variance into its two components, (*a*) that due to the

regression formula and (*b*) that due to deviations from the regression function and determining by means of the 'Z' test [Fisher, 1925] whether the mean values of the two were significantly different. All the four coefficients were found to be significant. For example, in the case of the lowest of them in the scale of significance, it was found that the odds in favour of its significance were over 12,000 to 1.

Minimum temperature (N) of the night and the dew point (P) of the air at 16 hrs. in the preceding afternoon.

The correlation coefficient between these two elements is +·72 in December-January and +·63 in February and is significant (Table II). The regression equation between the two elements expressed in terms of the actual temperatures instead of departures is :—

(1) December-January

$$N = \cdot 427\,P + 21\cdot 5 \quad \ldots \quad (v)$$

(2) February

$$N = \cdot 391\,P + 28\cdot 5 \quad \ldots \quad (vi)$$

The standard errors of the estimates of N from (v) and (vi) are 2·6°F and 3·3°F respectively.

A relation between the dew point and the minimum temperature of the night may be expected from general physical principles. In the night a layer of air loses heat by radiation and conduction to its surroundings in consequence of which, it progressively falls in temperature. When its temperature has reached the dew point, the water vapour in it may begin to condense and on account of the liberation of the latent heat of condensation, further fall in its temperature may either be arrested or at least the rate of fall of temperature may decrease. For example, on the mean of the whole period of record under examination, the minimum temperature was less than 0·1°F, higher than the dew point.

Minimum temperature (N) of the night and wet bulb temperature (W) of the air in the preceding afternoon.

The correlation coefficient between the minimum temperature of the night and wet bulb temperature of the preceding afternoon at Lahore is +·72 in December-January and +·80 in February and is highly significant (Table II). The regres-

sion equation expressed in terms of the actual temperatures under reference instead of their departures is :—

(*a*) December-January

$$N = \cdot 735\,W - 2\cdot 3 \quad \text{(vii)}$$

The standard error of the estimate is 2·6°F.

(*b*) February

$$N = \cdot 843\,W - 3\cdot 9 \quad \text{(viii)}$$

The standard error of the estimate is 2·5°F.

Equations vii and viii are simpler than equations xi and xii (given below) containing two independent variables, and give equally good results. The reason is that the wet bulb is far more important than the other independent variable (*i.e.* dry bulb temperature) used in equations xi and xii. In any individual case, the values of the minimum temperature may profitably be calculated from the relevant equations in each of the two pairs of equations and compared.

Multiple correlation coefficient between minimum temperature (N) of the night as dependent and dew point (P) and dry bulb temperature (D) of the air in the preceding afternoon as independent variables is +·73 in December-January and +·81 in February. The corresponding regression equations expressed in terms of the actual temperatures are :—

(*a*) December-January

$$N = \cdot 392\,P + \cdot 116\,D + 14\cdot 8 \quad \text{(ix)}$$

(*b*) February

$$N = \cdot 260\,P + \cdot 395\,D + 4\cdot 9 \quad \text{(x)}$$

The multiple correlation coefficient between minimum temperature (N) of the night as dependent and dry bulb (D) and wet bulb (W) temperatures of the air in the preceding afternoon as independent variables is +·73 for December-January and +·81 for February. The corresponding regression equations expressed in terms of actual temperatures are :—

(*a*) December-January

$$N = \cdot 837\,W - \cdot 130\,D + 0\cdot 9 \quad \text{(xi)}$$

(*b*) February

$$N = \cdot 322\,W + \cdot 0150\,D - 3\cdot 8 \quad \text{(xii)}$$

The standard error of estimate of N from each of the four equations ix to xii is about the same, namely ± 2·5°F, the probable error being ± 1·7°F. As might be expected the two pairs of equations (ix, x) and (xi, xii) give equally accurate results and the values of the minimum temperature calculated therefrom agree fairly closely with the observed values. The difference between the observed and calculated values for the two pairs of equations are given in Table III in the columns marked A and B respectively for reference.

If a difference of 4°F, (which is about $1\frac{1}{2}$ times the standard error of the estimate) between the observed and calculated values be neglected, the number of

cases in which this difference was not exceeded in case of each of the equations ix to xii is given below :—

Period	Equation	Cases of difference of 4° F or less (X)	Total No. of Observations (Y)	$\frac{X}{Y}$ Per cent.
December-January (1920-29) .	ix	137	144	95
Ditto do. . .	xi	139	144	96·5
February (1915-29) . . .	x	89	100	89
Ditto . . .	xii	89	100	89
All months December-February .	ix, x	226	244	92·5
Ditto do. . .	xi, xii	228	244	93·5

The maximum value of the difference under reference is 7°F ; it occurred in February twice with equation xii and only once with equation x in one hundred observations.

It has been tacitly assumed in this discussion that there is no change in the supply of the air at the station between the time of observation and the epoch of minimum temperature. If a change occurs, *e.g.*, if the air at the time of observation is replaced either by warmer and more humid or colder and drier air, large discrepancies in the observed and calculated values of minimum temperature may be expected, since the observed values of dew point, wet bulb and dry bulb temperatures used in the equations will be no longer applicable to the air mass in which the minimum temperature of the night occurs. Such changes in the air supply in winter are mostly associated with western disturbances or depressions which generally affect the station more frequently in February than in December or January.

A. Angstrom [1920], by making approximate assumptions regarding the rate of cooling of the air at night, has deduced theoretical expressions for the minimum temperature in terms of the dew point (P), wet bulb (W), and dry bulb (D) readings in the preceding evening. His expressions are :

$$N = AP + BD + K \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (a)$$

$$\& \; N = A'W + B'D + K' \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (b)$$

Here A, A′, B, B′, K and K′ are constants which may vary from place to place, and month to month. Equations ix and x are similar in form to expression (*a*) and equations xi and xii to (*b*). Thus the equations ix to xii developed in

this paper statistically have a physical significance. If A′ is very much larger than B′, so that the effect of the term involving B′ becomes comparatively smaller, the expression (*b*) takes the form—

$$N = A'W + K'' \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (c)$$

Equations vii and viii are similar in form to (*c*). A′ is about fifty five times B′ in equation xii and about six and a half times in equation xi.

Minimum temperature and the pressure distribution.

One of the most important features of the pressure distribution over northern India in the cool season is the western disturbances or depressions which travel eastwards across northern India at the average rate of 300—400 miles per day. These disturbances are often occluded and are ill-defined on the synoptic charts. When well-marked, they generally show sharp warm and cold fronts like the depressions of the temperate latitudes. When Lahore is in the warm sector of the disturbance, the air is warm and moist. The wind is from some easterly to southerly direction and the skies are cloudy. Frost does not occur under these conditions. With the passage of the cold front, the southerly to easterly winds are replaced by westerly to northwesterly winds, much stronger, colder and drier than the normal northwesterly winds of the season. These unusually cold winds blow in the rear of the disturbance for about a couple of days when the skies are also clear. Under the combined effect of these cold winds and strong radiation from the ground at night the minimum temperature may fall down to the freezing point.

Frost may also occur during unusually long spells of dry and clear (anticyclonic) weather as a result of the cumulative effect of radiation from the ground on successive clear nights.

Conclusions.

The foregoing discussion of Lahore afternoon temperatures shows that frost occurs at the station in winter either in the cold wave in the rear of a western disturbance or during unusually long spells of clear and dry (anticyclonic) weather. Within about $\pm 2°C$. the minimum temperature of the air on a clear night at Lahore can be forecasted from the wet bulb and dry bulb temperatures of the previous afternoon with an accuracy of over 93 per cent. The best equations to be used for the purpose are equations Nos. ix to xii. Equations vii and viii give equally good results and have the further advantage of containing only one independent variable. Equations Nos. i to iv also give satisfactory results and are quite useful as checks on the values obtained from equations vii to xii. The discrepancies observed in the remaining 6 or 7 per cent. cases are not large and are

mostly associated with the changes in the supply of the air at the station after the time of observations due to rapidly moving western disturbances. On such occasions, the afternoon temperature observations are not characteristic of the air in which the minimum temperature of the night occurs. A forecaster, provided with the facilities of the synoptic chart of the Indian forecasting area, can, in most cases, foresee and make an allowance for such occasions. On account of the importance of minimum temperature forecasts to agriculturists, the need of regular and accurate afternoon observations of temperature under standard conditions of exposure at all agricultural centres is obvious. The constants of the formulæ developed in this paper should be determined for each locality. If this is done, losses through damaging frosts and harmfully low temperatures could be reduced enormously by adopting protective measures in time.

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TABLE III.

Values of minimum temperature (N) *and of the dew-point* (P), *wet bulb* (W) *and dry bulb* (D) *temperatures of the air at 16 hrs. (local time) in the preceding afternoon at Lahore in December (1920-29), January (1920-29) and February (1915-29).*

Date	Temperature in °F				Minimum temperature calculated minus observed (°F)	
	Dew-point (P)	Dry-bulb (D)	Wet-bulb (W)	Minimum (N)	A from equations IX & X	B from equations X & XII
1	2	3	4	5	6	7
4th January 1925 . .	46	68	57	41	0	—1
6th „ „ . .	34	62	50	36	—1	—1
9th „ „ . .	41	65	54	39	—1	—2
10th „ „ .	44	67	55	40	0	—2
11th „ „ . .	43	67	55	41	—2	—3

TABLE III—*contd.*

Date	Temperature in °F				Minimum temperature calculated minus observed (°F)	
	Dew-point (P)	Dry-bulb (D)	Wet-bulb (W)	Minimum (N)	A from equations IX & X	B from equations XI & XII
1	2	3	4	5	6	7
12th January 1925	39	67	54	36	2	1
13th ,, ,,	34	66	52	35	1	1
14th ,, ,,	28	65	50	35	—2	—1
15th ,, ,,	34	67	52	37	—1	—1
22nd ,, ,,	35	58	48	35	0	—2
23rd ,, ,,	30	61	48	37	—3	—4
28th ,, ,,	36	59	49	37	—1	—3
29th ,, ,,	29	63	49	36	—3	—2
30th ,, ,,	33	65	51	36	—1	—1
8th ,, 1926	49	64	56	42	—1	—3
9th ,, ,,	48	65	56	42	—1	—3
17th ,, ,,	47	67	57	41	0	—1
18th ,, ,,	35	67	53	37	—1	—1
20th ,, ,,	36	69	54	36	1	1
21st ,, ,,	40	70	56	40	—1	—1
24th ,, ,,	46	71	58	41	0	—1
25th ,, ,,	44	72	58	42	—2	—2
14th ,, 1927	39	64	53	35	2	2
15th ,, ,,	38	66	53	35	2	1
16th ,, ,,	37	67	53	36	1	0
17th ,, ,,	37	69	54	35	2	2
19th ,, ,,	38	68	54	41	—3	—4
20th ,, ,,	40	71	56	38	1	0
21st ,, ,,	40	70	55	40	0	—2

TABLE III—*contd.*

Date	Temperature in °F				Minimum temperature calculated minus observed (°F)	
	Dew-point (P)	Dry-bulb (D)	Web-bulb (W)	Minimum (N)	A from equations IX & X	B from equations XI & XII
1	2	3	4	5	6	7
22nd January 1927 . .	41	70	56	41	—2	—2
25th ,, ,, . .	39	68	54	36	2	1
9th ,, 1928 . .	50	70	59	44	—2	—3
10th ,, ,, . .	47	69	58	40	1	0
21st ,, ,, . .	41	64	53	40	—2	—3
4th ,, 1929 . .	42	67	55	41	—2	—3
5th ,, ,, . .	45	69	57	38	2	1
6th ,, ,, . .	44	69	56	38	2	1
10th ,, ,, . .	43	70	57	40	0	—1
18th ,, ,, . .	44	70	57	40	0	—1
19th ,, ,, . .	37	69	54	37	0	0
20th ,, ,, . .	43	69	56	37	3	2
21st ,, ,, . .	35	69	54	41	—5	—4
30th ,, ,, . .	18	50	39	29	—1	—2
31st ,, ,, . .	23	53	42	32	—2	—3
6th ,, 1927 . .	39	67	54	39	—1	—2
7th ,, ,, . .	42	65	54	37	2	0
8th ,, ,, . .	38	63	51	34	3	1
9th ,, ,, . .	39	66	53	33	4	3
10th ,, ,, . .	33	67	52	32	3	3
11th ,, ,, . .	36	65	52	33	3	3
1st December 1925 . .	48	75	61	40	2	2
2nd ,, ,, . .	47	76	61	41	1	1
3rd ,, ,, . .	46	76	60	41	1	0

TABLE III—*contd.*

Date	Temperature in °F				Minimum temperature calculated minus observed (°F)	
	Dew-point (P)	Dry-bulb (D)	Wet-bulb (W)	Minimum (N)	A from equations IX & X	B from equations XI & XII
1	2	3	8	5	6	7
4th December 1925 . .	48	76	61	41	1	1
5th „ „ . .	53	74	62	43	1	0
6th „ „ . .	53	74	62	42	2	1
9th „ „ . .	48	72	59	41	1	0
10th „ „ . .	48	72	59	39	3	2
11th „ „ . .	48	71	59	39	3	2
12th „ „ . .	49	72	59	40	2	1
14th „ „ . .	49	70	59	41	1	0
15th „ „ . .	48	69	58	40	2	0
16th „ „ . .	50	69	59	39	3	2
17th „ „ . .	47	70	58	38	3	2
18th „ „ . .	42	72	57	36	3	3
19th „ „ . .	44	72	58	35	5	4
20th „ „ . .	43	68	56	35	4	4
26th „ „ . .	44	68	56	37	3	2
27th „ „ . .	43	68	56	36	3	3
28th „ „ . .	42	71	56	35	4	3
29th „ „ . .	43	71	57	36	4	3
30th „ „ . .	44	70	57	37	3	2
9th „ 1926 . .	54	71	62	45	—1	—2
15th „ „ . .	47	66	56	43	—2	—4
16th „ „ . .	46	67	57	40	1	0
19th „ „ . .	39	69	55	38	0	0
20th „ „ . .	41	68	55	37	2	1

TABLE III—*contd.*

Date	Temperature in °F				Minimum temperature calculated minus observed (°F)	
	Dew-point (P)	Dry-bulb (D)	Wet-bulb (W)	Minimum (N)	A from equations IX & X	B from equations XI & XII
1	2	3	4	5	6	7
21st December 1926	43	68	55	37	2	1
22nd „ „	36	69	54	34	3	3
24th „ „	34	68	53	35	1	1
27th „ „	37	71	55	34	3	4
28th „ „	39	69	55	36	2	2
29th „ „	40	71	56	35	4	3
30th „ „	41	73	57	36	3	3
31st „ „	37	74	56	36	2	2
16th „ 1927	43	71	57	38	2	1
22nd „ „	53	69	60	45	—2	—3
4th „ 1928	47	63	55	43	—2	—4
5th „ „	44	63	54	40	—1	—2
8th „ „	50	67	58	44	—2	—4
17th „ „	47	68	57	41	0	—1
18th „ „	39	70	55	39	—1	—1
19th „ „	43	70	57	39	1	0
20th „ „	50	71	60	41	2	1
21st „ „	49	68	58	40	2	0
23rd „ „	48	72	59	41	1	0
31st „ „	45	61	53	39	0	—2
1st „ 1929	45	75	60	43	—2	—2
28th „ „	35	61	50	35	0	0
15th „ 1927	55	68	61	49	—5	—6
1st „ 1920	38	78	58	45	—6	—6

TABLE III—*contd.*

Date	Temperature in °F				Minimum temperature calculated minus observed (°F)	
	Dew-point (P)	Dry-bulb (D)	Wet-bulb (W)	Minimum (N)	A from equations IX & X	B from equations X& XII
1	2	3	4	5	6	7
2nd December 1920 . .	48	77	62	44	—1	—1
3rd „ „ . .	45	77	60	45	—4	—4
4th „ „ . .	39	74	57	42	—3	—3
5th „ „ . .	35	71	54	40	—3	—3
9th „ „ . .	40	75	57	38	1	1
10th „ „ . .	38	73	56	36	2	2
11th „ „ . .	39	72	56	37	1	1
12th „ „ . .	40	73	57	37	2	2
13th „ „ . .	42	76	59	38	3	2
14th „ „ . .	40	75	58	40	—1	—1
31st „ „ . .	35	70	54	36	1	1
6th „ 1921 . .	57	73	64	49	—3	—4
7th „ „ . .	53	70	61	47	—3	—4
8th „ „ . .	51	70	60	44	—1	—2
5th „ 1922 . .	50	76	62	48	—5	—5
8th „ „ . .	53	74	62	47	—3	—4
25th „ „ . .	44	63	53	38	1	—1
31st „ „ . .	35	64	51	37	—1	—2
12th „ 1923 . .	33	67	52	37	—2	—1
20th „ „ . .	45	71	58	41	0	—1
21st „ „ . .	41	71	56	41	—2	—3
24th „ „ . .	48	71	59	45	—3	—4
25th „ „ . .	47	72	59	43	—1	—2
26th „ „ . .	44	71	57	41	—1	—2

TABLE III—*contd.*

Date	Temperature in °F				Minimum temperature calculated minus observed (°F)	
	Dew-point (P)	Dry-bulb (D)	Wet-bulb (W)	Minimum (N)	A from equations IX & X	B from equations XI & XII
1	2	3	4	5	6	7
27th December 1923 . .	38	69	55	39	—1	—1
28th „ „ . .	31	69	52	38	—3	—3
29th „ „ . .	35	70	54	37	0	0
31st „ „ . .	34	70	54	38	—2	—1
18th „ 1924 . .	49	70	59	44	—2	—3
19th „ „ . .	47	67	57	45	—4	—5
2nd January 1920 . .	46	68	57	39	2	0
6th „ „ . .	49	68	58	41	1	—1
7th „ „ . .	47	71	58	38	3	2
17th „ „ . .	51	68	59	42	1	—1
18th „ „ . .	47	69	58	41	0	—1
25th „ „ . .	46	64	55	42	—2	—3
8th „ 1921 . .	37	73	56	40	—2	—2
16th „ „ . .	44	69	57	44	—4	—4
17th „ „ . .	40	66	54	37	1	0
23rd „ „ . .	43	69	56	44	—4	—5
27th „ „ . .	46	71	58	41	0	—1
30th „ „ . .	36	73	55	40	—3	—3
29th „ 1923 . .	51	70	60	46	—3	—4
			February			
3rd February 1923 . .	42	71	57	39	5	5
5th „ „ . .	25	67	50	42	—4	—4
6th „ „ . .	28	70	52	39	1	1
11th „ „ . .	33	61	49	38	0	0

TABLE III—*contd.*

Date	Temperature in °F				Minimum temperature calculated minus observed (°F)	
	Dew-point (P)	Dry-bulb (D)	Wet-bulb (W)	Minimum (N)	A from equations IX & X	B from equations XI & XII
1	2	3	4	5	6	7
12th February 1925	31	60	48	39	—2	—2
13th „ „	27	66	50	37	1	1
14th „ „	33	71	54	46	—4	—4
16th „ „	45	68	56	48	—4	—5
17th „ „	33	63	50	44	—6	—6
23rd „ „	28	72	53	37	4	4
3rd „ 1926	55	71	62	48	—1	0
4th „ „	43	71	57	45	—1	—1
7th „ „	43	69	56	42	1	1
16th „ „	44	74	59	42	4	4
17th „ „	33	72	54	41	1	1
20th „ „	43	75	59	45	1	1
23rd „ „	47	81	63	49	0	0
25th „ 1927	33	67	53	39	1	2
16th „ 1928	49	73	60	47	—1	0
17th „ „	43	75	59	45	1	1
20th „ „	48	79	62	50	—1	—2
21st „ „	46	81	62	51	—2	—3
22nd „ „	45	82	62	48	1	0
23rd „ „	42	80	61	48	0	—1
4th „ 1929	35	64	51	36	3	3
16th „ „	40	71	56	43	0	0
17th „ „	43	72	57	42	3	2
19th „ „	43	75	59	46	0	0

TABLE III—*contd.*

Date	Temperature in °F				Minimum temperature calculated minus observed (°F)	
	Dew-point (P)	Dry-bulb (D)	Web-bulb (W)	Minimum (N)	A from equations IX & X	B from equations XI & XII
1	2	3	4	5	6	7
26th February 1927	32	70	53	41	0	0
27th „ „	28	73	53	46	—5	—5
10th „ 1920	39	59	50	38	0	0
11th „ „	36	63	51	39	0	0
14th „ „	47	69	58	41	3	4
15th „ „	43	74	58	44	1	1
5th „ 1921	39	65	53	39	2	2
6th „ „	38	67	54	39	2	3
8th „ „	37	71	55	42	1	1
9th „ „	24	68	50	37	1	1
14th „ „	32	73	55	45	—3	—2
15th „ „	30	76	56	45	—2	—2
16th „ „	33	79	58	45	0	0
17th „ „	36	81	59	45	1	1
18th „ „	35	83	60	48	—1	—1
19th „ „	40	85	62	48	1	0
20th „ „	42	86	63	48	2	1
6th „ 1922	46	70	58	43	2	2
7th „ „	44	72	58	43	2	2
8th „ „	48	73	60	49	—3	—2
9th „ „	45	77	61	50	—3	—3
16th „ „	51	79	63	49	0	0
25th „ „	46	78	61	53	—5	—5
26th „ „	42	78	60	47	0	0

TABLE III—*contd.*

Date	Temperature in °F				Minimum temperature calculated minus observed (°F)	
	Dew-point (P)	Dry-bulb (D)	Web-bulb (W)	Minimum (N)	A from equations IX & X	B from equations XI & XII
1	2	3	4	5	6	7
26th February 1923 . .	45	70	57	47	—3	—3
10th „ 1924 . .	45	63	54	41	0	1
11th „ „ . .	42	65	54	43	—2	—1
15th „ „ . .	41	68	55	42	0	1
16th „ „ . .	37	71	55	43	0	0
17th „ „ . .	42	71	56	50	—6	—7
18th „ „ . .	39	74	57	44	0	0
19th „ „ . .	39	76	58	45	0	0
20th „ „ . .	44	79	61	47	1	0
21st „ „ . .	45	78	61	49	—2	—2
1st „ 1919 . .	48	62	55	43	—1	—1
5th „ „ . .	48	67	57	43	1	1
6th „ „ . .	40	69	55	41	2	2
13th „ „ . .	41	76	59	45	0	1
21st „ „ . .	48	75	61	46	1	1
2nd „ 1918 . .	36	72	55	38	5	4
3rd „ „ . .	34	71	54	36	6	6
4th „ „ . .	32	69	53	37	4	4
7th „ „ . .	36	73	56	38	5	5
8th „ „ . .	33	73	55	45	—3	—2
14th „ „ . .	46	75	60	46	1	1
15th „ „ . .	45	76	60	44	3	3
16th „ „ . .	38	77	58	44	1	1
17th „ „ . .	41	78	59	45	1	1

TABLE III—*concld.*

Date	Temperature in °F				Minimum temperature calculated minus observed (°F)	
	Dew-point (P)	Dry-bulb (D)	Web-bulb (W)	Minimum (N)	A from equations IX & X	B from equations XI & XII
1	2	3	4	5	6	7
1st February 1917 . .	37	73	56	38	5	5
5th „ „ . .	42	72	57	41	3	3
10th „ „ . .	38	74	57	42	2	2
11th „ „ . .	39	76	58	44	1	1
16th „ „ . .	52	81	65	52	—1	—1
17th „ „ . .	54	85	67	53	0	—1
18th „ „ . .	50	83	65	53	—2	—2
22nd „ „ .	41	77	59	47	—1	—1
23rd „ „ . .	32	74	55	39	4	4
24th „ „ . .	38	77	58	43	2	2
25th „ „ . .	33	78	57	44	0	0
26th „ „ . .	34	79	58	48	—3	—3
2nd „ 1916 . .	44	74	59	47	—1	—1
3rd „ „ . .	37	74	56	44	0	—1
4th „ „ . .	41	70	56	50	—7	—7
5th „ „ . .	20	65	47	41	—5	—5
6th „ „ . .	30	57	46	36	—1	—1
7th „ „ . .	27	60	47	34	2	2
21st „ „ . .	42	76	59	46	0	0
26th „ „ . .	49	76	61	49	—1	—2
27th „ „ . .	40	76	58	49	—4	—4
28th „ „ . .	32	78	57	44	0	0
23rd „ 1915 . .	44	75	59	46	0	0
24th „ „ . .	40	75	58	47	—2	—2

SOME STUDIES IN RESPIRATION AND OTHER METABOLIC ACTIVITIES IN BERRIES OF THE GRAPE VINE (*VITIS VINIFERA*, LINN).

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INTRODUCTION.

The investigation reported in the paper relates to the study of respiration and other metabolic activites in grape berries from the time of bearing to maturity. The work was carried out in 1929 in the Botanical laboratory, Punjab Agricultural College, Lyallpur. So far as the authors have been able to trace by the study of literature on the subject, it appears that the following brief references point to the work done on metabolic processes in plants including fruits.

Ludwig Jost [1907] holds that protoplasm is the seat of respiration and mentions that even the same organ of an individual plant in different stages of development exhibits the widest possible variation as far as the respiratory activity is concerned. "Flowers, embryonic organs, germinating seeds, buds, etc., appear to respire more vigorously than full grown roots, stems or leaves." Palladin [1921] says "On the amount of protoplasm present in a tissue depends the amount of enzymes and the latter determine the rate of respiration as long as the supply of carbohydrates is adequate. Kidd, West and Briggs [1921] have witnessed a fall in the respiratory index of *Helianthus annus* and of its various parts with the increase in age.

Blackman and Parija [1928] state, "Any change that takes place in the metabolic activity of the cell must run in close parallel with the corresponding change in the respiration of that cell". Richards [1896] observed an increase in the respiratory activity after injury to plant tissue. He ascribes this increased respiration to an effort on the part of the plant to recover from the injury. Luthra [1924] while studying the effects of dry and moist air on the rate of respiration and break-

down of ripe pears found that dry air hastened the rate of break-down as compared with moist air. The rate of respiration showed a marked decline with the lapse of time. Archbold [1925] holds that a high nitrogen content in general is accompanied by a high respiration rate and during storage other factors besides nitrogen content come into play which diminish the respiration rate. Gore [1911] says "The rate of respiration is not a direct function of content of sugars or of acids and does not depend on size, as Japanese Persimons are richer in sugars than strawberries, yet are less active; oranges and lemons, which differ greatly in acid contents, have about the same respiratory activity. Red currants differ greatly in respiratory activity from black currants although they are nearly the same in size." Spoehr and Megee [1923] hold that "A carbohydrate content alone cannot be taken as an index of the rate of respiration". According to them presence of amino acids in a tissue determines its respiratory activities. Appleman [1916] found an invariable parallelism between the respiratory intensity of sweet corn and the Catalase activities in the expressed juice.

Scheme of the investigation.

The subject has been studied in the following respects :—

A. Determination of the rate of respiration of grape berries of different ages.

These estimations were made in the laboratory (1) on bunches removed from the plant and (2) *in situ i.e.*, while the bunches were on the plant. Experiments on grape bunches *in situ* were carried on during the day from 6 A.M. to 12 noon and at night from 9 P.M. to 3 A.M.

B. A biochemical study of metabolic changes throughout the life-cycle from the time of bearing to maturity. The following determinations were made at intervals.

1. Total solids.
2. Total reducing sugars.
3. Total titrable acids.
4. Nitrogen contents.
5. Water-insoluble residue.
6. Specific gravity of the juice.
7. Cellulose.

C. Study of correlation between the rate of respiration and sugars. Determination of co-efficient of correlation between sugars and acids.

(A) Studies on Respiration.

The work was undertaken to discover if there was any correlation between the intensity of respiration and the biochemical changes that occur in grape berries dur-

ing the process of maturation. The nature of the problem necessitated a study of the activity of respiration and chemical changes in developing grape berries. For this purpose two Indian varieties of grape vines named *jaishi* and *tur*, growing in the vineyard of the Botanical Section, Punjab Agricultural College, Lyallpur, were selected. These varieties were introduced from Peshawar in 1910. Berries of *jaishi* are white and oblong and those of *tur* are black and round. Flowers appeared about the 20th of March and bunches were labelled as soon as the berries had set. Exact age of the bunches was known when they were subjectsd to physiological studies.

Apparatus employed.—The method employed for determining the rate of respiration was one of gaseous exchange. A constant current of air free of carbon dioxide was maintained through a respiration chamber by means of a suction pump connected with a water tap and controlled by a mercury pressure regulator. The current of air entering the respiration chamber was cleared of carbon dioxide by passing through a soda lime tower and a series of bottles containing 20 per cent. sodium hydroxide solution. Before entering the respiration chamber, the air was let through a small bottle containing barium hydroxide. The absence of any precipitate ensured that the air was completely freed of CO_2. Carbon dioxide evolved by the berries was absorbed in a known quantity of standardized $\frac{N}{10}$ NaOH solution filled in Reiset towers. Air escaping from the Reiset tubes was again tested for the complete absorption of CO_2 by barium hydroxide.

Experimental procedure.—In order to map out variations in the respiratory activity of grape berries as influenced by metabolic changes, entire bunches of known age were removed from time to time and taken to the laboratory for the determination of the rate of respiration. Bunches were taken for the estimation of respiration because it was feared that removal of berries alone would make them more liable to a fungus attack and wounding was likely to augment the CO_2 output. The bunch was weighed before and after the experiment and loss in weight was recorded each time. It was then quickly transferred to the respiration chamber, which had been previously exhausted of CO_2 by running the apparatus empty for 8 hours. After putting in the bunch, the apparatus was again run for half an hour. Reiset tubes were then connected with the respiration chamber. For each determination, the experiment was run for not less than 22 hours.

During the course of these estimations, care was taken to keep the apparatus air-tight. Respiration chamber was always kept covered by a piece of black cloth to stop carbon assimilation. The bottles containing 20 per cent. NaOH solution used for rendering the air free of carbon dioxide before it entered the chamber, were changed from time to time.

The determinations were made at the room temperature, which varied as the season advanced (Table III-A); care being, however, taken to keep the temperature as uniform as possible during the course of each determination by immersing the respiration chamber in a water bath. The temperature, in this manner, was kept constant to within two degrees, during the experiment.

At the close of the experiment, Reiset tubes were thoroughly washed with boiled distilled water. The CO_2 given out was quantitatively estimated by titrating the solution against N H_2SO_4 using phenolphthalein and methyl orange as indicators. The amount of NaOH used up in the reaction was ascertained and from this total CO_2 evolved during the duration of the experiment was worked out.

To eliminate any possible error due to washing of the absorption tubes and traces of CO_2 finding their way from the air, the apparatus was run for 24 hours periodically as a control. The NaOH in the absorption tubes was titrated and the amount of alkali used up in this way was subtracted from that taken up by the CO_2 evolved by the berries. The results were expressed on initial weight of the berries as c. c. of CO_2 evolved per 100 grms. of berries per hour.

Results.

Determinations of respiratory activity were begun, when berries were two days old in the case of *jaishi* and about five days old in the case of *tur*. At these stages berries had attained an appreciable size fit for handling. Experiments were carried on till berries had completely matured. The results are given in Table I and the range of variation is illustrated in graph Fig. 1.

It appears from the data that respiration was very active, when berries were young, but the rate gradually slowed down and became fairly constant later, as berries advanced in age. The rate of respiration declined very rapidly during the first thirty days after setting; after which period the decline was not so well pronounced. On the 35th and 52nd day a slight rise is noticeable. This was due to the fact that some of the berries, during the course of the experiment, were attacked by a mould and caused fermentation. The bunches were taken out, respiration chamber was sterilized and experiments were started again. After that, no such fluctuations occurred and the curve shows a steady fall till the respiratory activity reaches a minimum. The minima in the curve correspond to complete maturity of the berries.

Reference to experimental evidence illustrates that the rate of respiration fell from 30·49 c. c. of CO_2 per hundred grms. per hour, when berries were young to 4·79 c. c. of CO_2 when berries had fully matured.

A similar fall in respiration rate was discovered in the case of the *tur* variety. Analytical data obtained in this case strictly corroborate that obtained in *jaishi*. The results are given in Table II and graphed in Fig. 1.

In 1930 the experiments were repeated and four determinations were made with three bunches of the same age in each lot. The results showed slight variations due to the difference of temperature, but on the whole corroborated the data of 1929.

TABLE I.

Showing the rate of respiration in the Jaishi *Vine throughout the life cycle of the berries.*

Date of commencement of the experiment	Age of berries in days	Duration of the experiment	Output of CO_2 in ccs. per 100 grms. of berries per hour
15th April 1929	2	22 hours	30·49
20th April 1929	5	24 „	20·27
24th April 1929	8	22 „	15·88
27th April 1929	10	24 „	11·86
6th May 1929	15	25 „	10·81
14th May 1929	20	24 „	7·47
18th May 1929	25	26 „	7·56
24th May 1929	30	24 „	7·26
26th May 1929	35	27 „	8·40
29th May 1929	40	28 „	6 99
30th May 1929	47	28 „	6·86
4th June 1929	52	26 „	7·57
7th June 1929	56	26 „	6·03
12th June 1929	60	27 „	5·97
16th June 1929	65	26 „	5·87
20th June 1929	70	23 „	4·85
25th June 1929	75	24 „	4·79

TABLE II.

Showing the rate of respiration of grape berries in the tur *Vine.*

Date of commencement of the experiment	Age of berries in days	Duration of the experiment	Output of CO_2 in ccs. per 100 grms. of berries per hour
25th April 1929	3	23 hours	25·69
30th April 1929	5	22 ,,	15·46
8th May 1929	15	25 ,,	13·61
20th May 1929	29	28 ,,	7·69
27th May 1929	36	24 ,,	9·27
1st June 1929	40	22 ,,	7·67
10th June 1929	50	26 ,,	7·37
14th June 1929	55	26 ,,	4·67

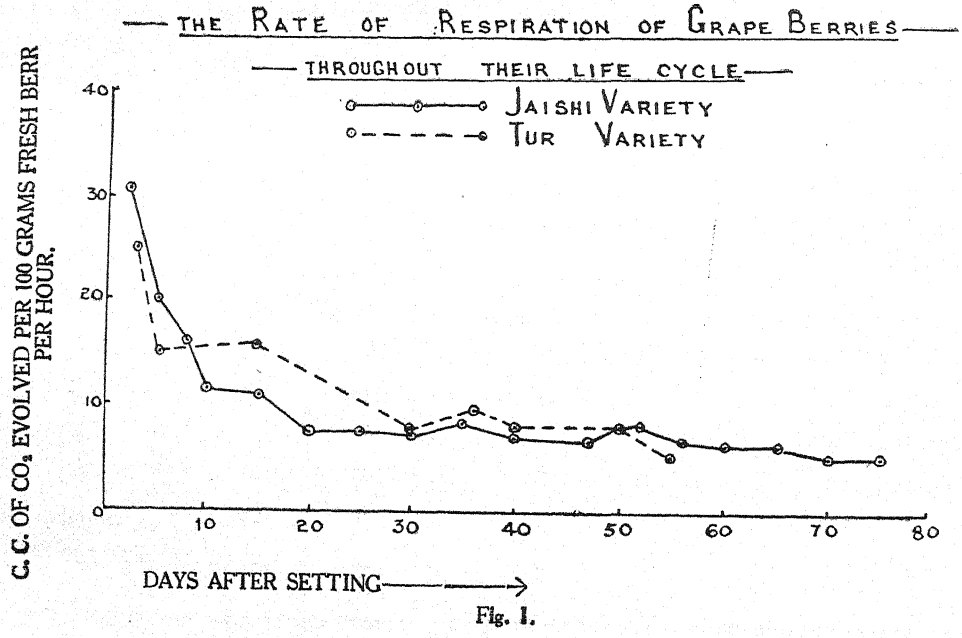

Fig. 1.

RESPIRATION OF GRAPE BERRIES *IN SITU* DURING DAY TIME.

Kidd, West and Briggs [1921] while studying respiratory index of detached parts of *Helianthus annus* determined respiration of an entire plant *in situ* in the field. They noticed a strict parallelism between the values obtained from cut and entire plant *in situ* to the extent that there was a continuous falling off in the respiration rate with age in both cases.

With a view to find out if such a bulky material as grape berries would yield similar results, the experiment referred to was conducted.

Apparatus used.—In the absence of a water tap in the field, an aspirator was employed in place of the suction pump, etc. Experience showed that the aspirator did not exert a sufficient force to draw in air through Reiset towers. Three bubblers with spiral tubes were therefore employed and each contained 100 c.c. of $\frac{N}{20}$ NaOH solution for the absorption of CO_2. The apparatus used for the removal of CO_2 from air entering the respiration chamber and the procedure adopted were the same as already described.

Experimental procedure.—Only one plant of *jaishi* variety was selected for this purpose. Bunches, which could be conveniently handled, were selected. The respiration rate was estimated once a week and was continued till the bunch was 68 days old. At this stage the experiment was stopped, because misleading values were obtained due to the appearance of a fungus on the berries. The bunch under investigation was carefully introduced into a wide mouthed glass bottle. A slit was kept in the cork through which peduncle of the bunch could pass. All joints were made air tight by wax. The plant chamber was then placed in a water bath and was kept covered by a piece of black cloth in order to keep out light. The apparatus was run empty for half an hour to expel CO_2 from the respiration chamber before CO_2 absorption bubblers were connected with the respiration chamber. After half an hour bubblers were attached to the plant chamber and the experiment was allowed to continue for six hours each time. Temperature of the plant chamber was taken occasionally by a thermometer inserted in the chamber (Table III). Reference to Table III shows that the average temparature varied only from 2 to 3 degrees during the course of determinations except on 20th April 1929 when it was 84 degrees F due to clouds but it shows a rapid rise from 6-7 A.M. to 12 Noon-1 P.M. in almost all the experiments.

At the close of experiment, the bunch was taken out and its volume was measured by water displacement method, because weighing was impracticable. The bubblers were taken to the laboratory, washed with boiled distilled water and CO_2 was quantitatively estimated by the method already described. The results were expressed as c.c. of CO_2 evolved per 100 c.c. of the bunch per hour.

Results.---The results obtained with detached bunches in the laboratory were also expressed on volume basis in order to make them strictly comparable with those got *in situ*. From the data compiled in Tables III and III-A and graphed in Fig.2, a close agreement between the values obtained in the field and laboratory is noticeable to the extent that respiratory activity shows a gradual decline as the berries mature. Values obtained in the laboratory and the field when the berries were 2 days old are identical and this is due to the average temperature in both the cases being nearly the same. In the field higher values are obtained for the determinations made on berries 8, 12, 19 and 26 days old than the corresponding figures got in the laboratory. Higher temperature in the field in those days seems to be responsibile for the increased respiratory activity there, since later on, when average temperature of the laboratory exceeded the average temperature in the field, as summer advanced, the results tended to be slightly higher in the case of laboratory. For practical purposes, however, the results are similar in both the cases and they are confirmed by the results of Kidd, West and Briggs.

Indirectly the results also confirm the view that there is greater respiratory activity with the rise of temperature.

TABLE III.

Showing the rate of respiration of grape berries in situ.

Date of commencement of the experiment	Age of berries in days	Average temperature of the chamber for the day Degrees F	Output of CO_2 in ccs. per 100 c.c. of berries per hour	Duration of the experiment in hours
20th April 1929 . . .	2	84	32·48	6
24th „ „ . . .	8	92·7	23·34	6
29th „ „ . . .	12	95·9	23·58	6
6th May „ . . .	19	91·2	18·98	5
14th „ „ . . .	26	94·0	12·48	6
21st „ „ . . .	33	90·6	8·54	6
28th „ „ . . .	40	89·5	5·83	6
4th June „ . . .	47	95·2	6·94	6
11th „ „ . . .	54	93·7	6·65	6
18th „ „ . . .	61	92	6·21	6
25th „ „ . . .	68	93·5	5·96	6

TABLE III-A.

Showing the rate of respiration of grape berries in the laboratory.

Date of commencement of the experiment	Age of berries in days	Average temperature of the chamber for the day Degrees F	Output of Co_2 C. C's per 100 cc of berries per hour	Duration of the experiment in hours
15th April 1929 . .	2	84·2	34·01	22
22nd April 1929 . .	5	85	24·0	24
24th April 1929 . .	8	84·2	16·45	22
27th April 1929 . .	10	86·2	11·97	24
6th May 1929 . .	15	89·1	10·94	25
14th May 1929 . .	20	90·6	7·01	24
18th May 1929 . .	25	91·8	7·55	26
24th May 1929 . .	30	93·8	7·53	24
26th May 1929 . .	35	93·9	8·65	27
29th May 1929 . .	40	96·2	7·13	28
30th May 1929 . .	47	97·3	6·91	28
4th June 1929 . .	52	99·6	7·96	26
7th June 1929 . .	56	96·2	7·02	26
12th June 1929 . .	60	100·1	6·11	27
16th June 1929 . .	65	94·2	6·03	26

RESPIRATION *IN SITU* DURING NIGHT.

These studies were further carried out to ascertain the behaviour of berries with regard to respiratory activity at night. Ten observations were made from time to time from 9 P.M. to 3 A.M.

Apparatus and experimental procedure.—The apparatus used and the method followed were exactly the same as already described except this that the experiment was conducted at night.

Results.—Data obtained are represented in Table IV and Fig. 2 Page 704. Examination of the values obtained during day and night reveals that under the conditions of the experiment there is no difference between the respiration rates in the two cases. The general form of the curves in both agrees with one another, but slightly low figures are obtained at night and this difference is evidently due to

lower temperature. In no case the average temperature exceeded 89° F but during the day time it was as high as 95°F.

TABLE IV.

Showing the rate of respiration in situ *at night.*

Date of commencement of the experiment	Age of berries in days	Average temperature in degrees from 9 P.M. to 3 A.M. Degrees F	Output of Co_2 per 100 cc of berries per hour	Duration of the experiment in hours
10th May 1929 . .	2	79·6	29·76	6
14th „ „ . .	6	79·5	22·36	6
21st „ „ . .	13	84·7	19·14	6
28th „ „ . .	20	74·2 showers of rain.	6·47	6
4th June 1929 . .	27	89·5 stormy.	7·90	6
11th „ „ . .	34	85·2	6·13	6
18th „ „ . .	41	84·2	5·65	6
25th „ „ . .	48	83·5	5·32	6
2nd July 1929 . .	56	84·7	4·47	6
9th „ „ . .	63	85·2	3·71	6

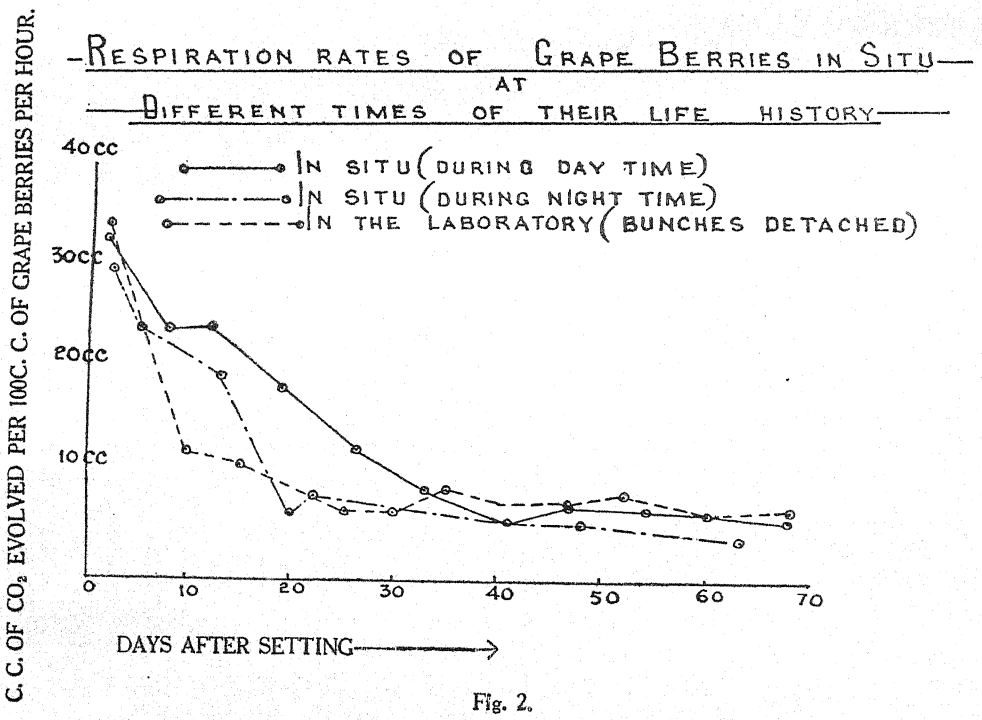

Fig. 2.

(B) Metabolic Changes.

Chemical changes accompanying the metabolic activities of grape berries during their life history were studied with reference to the following constituents.

1. Total solids.
2. Reducing sugars.
3. Total titrable acids.
4. Nitrogen.
5. Water-insoluble residue.
6. Specific gravity of the juice.
7. Cellulose.

Methods employed for the estimation of the above constituents and the results obtained were as follows :—

1. *Total solids.*—The amount of dry matter present in the berries at different times during their growth was estimated every week. A known weight of berries was placed in an oven, at a temperature of 90°C. Of course it is not possible to completely dry the sample at this temperature but heating beyond 90°C is likely to lead to the decomposition of sugars, so this temperature was never exceeded. The best method for estimating the amount of dry matter in the berries would have surely been that of drying them in a vacuum oven but arrangements could not be made for it.

Results.—Table V below gives the variation in the dry matter for both *jaishi* and *tur* varieties. Looking at the figure for *jaishi* it will be seen that the percentage of dry matter on the 3rd day after setting is rather high, then it goes on decreasing till about the 3rd week, when it continues to rise gradually up to the end of the ripening period. It is rather difficult to explain the excess of dry matter during the first week of setting, since as it will be noticed later on, the amount of cellulose material is almost constant throughout the life cycle of the fruit. This probably means that the percentage amount of proteins and sugars and other non-cellular material is much less in the beginning.

The excess of dry matter in the initial stage is also noticeable in the case of the *tur* variety. From about the second week onward the total solids, however, show a steady increase uptil the end. The results are represented in fig. 3.

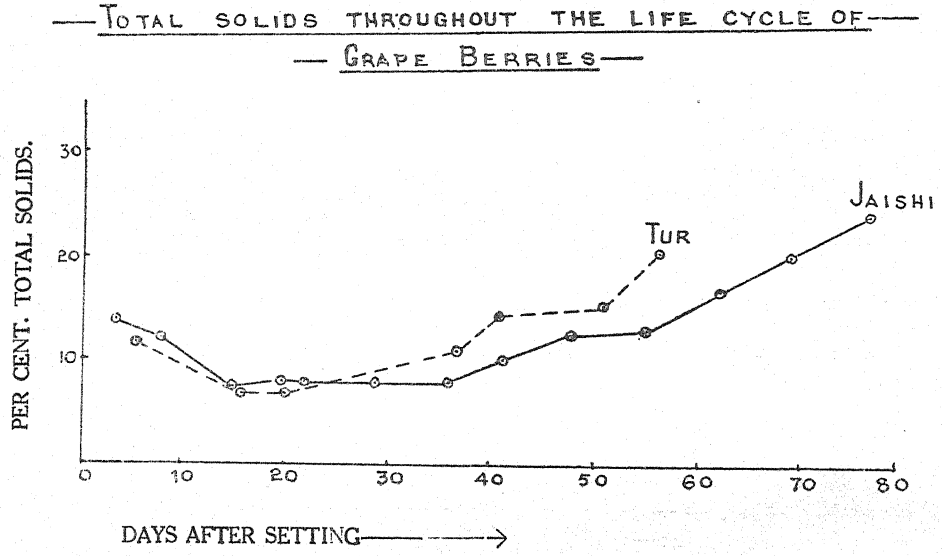

Fig. 3.

TABLE V.

Showing percentage of total solids in grape berries of both the varieties at different ages.

Jaishi			*Tur*		
Date of estimation	Age of berries in days	Percentage of total solids	Date of estimation	Age of berries in days	Percentage of total solids
15th April 1929 .	3	13·75	28th April 1929 .	5	11·47
19th April 1929 .	7	11·73	3rd May 1929 .	15	6·71
26th April 1929 .	14	7·48	10th May 1929 .	19	7·29
30th April 1929 .	19	7·83	20th May 1929 .	29	9·41
3rd May 1929 .	21	8·0	27th May 1929 .	36	11·30
10th May 1929 .	28	8·4	3rd June 1929 .	40	13·73
17th May 1929 .	35	8·45	10th June 1929 .	50	15·25
23rd May 1929 .	40	9·97	17th June 1929 .	55	20·31
30th May 1929 .	47	12·62			
6th June 1929 .	54	13·30			
13th June 1929 .	61	16·65			
20th June 1929 .	68	20·25			
27th June 1929 .	75	23·75			

2. *Reducing sugars.*—In the early stages, berries of both the *jaishi* and *tur* grape vines are green in colour and it was expected that prior to formation of sugars there would be starch produced. But microscopic examination and chemical tests failed to reveal the presence of starch grains. It appears that sugars are the direct product of carbon assimilation.

Before reducing sugars can be estimated, it is necessary to obtain the juice in a suitable form. For this purpose the method recommended by Haynes [1925] was used. A known amount of berries was rammed down into silver-plated metal cylinders and left over night in freezing mixture. Next morning the berries along with the juice that had come out during the night, were crushed in a pestle-mortar and the entire mass ground to a fine pulp and transferred to a 250 c. c. flask with the help of distilled water. The juice was clarified by the addition of basic lead acetate and stirred. The flask after being shaken thoroughly was allowed to stand for 10 to 15 minutes, so that proteins and other allied bodies may settle down. In order to remove the excess of lead, powdered sodium carbonate was added till the solution was just alkaline. The solution was now made up to the mark, well shaken and filtered. The first portions of the filtrate were again transferred to the filter paper, till a clear solution was obtained. This juice was used for the estimation of reducing sugars, which was done as follows.

20 c.c. of the Fehling's solution were prepared according to the method of (Ling and Jones) and were titrated against the juice obtained from the berries as described above and diluted to a suitable strength. Ferrous ammonium sulphate and ferrous thiocyanate were used as external indicator. The end point was detected by bringing a drop of the reacting mixture on to a marble slab in contact with the above indicator. Absence of any red colour indicated the completion of titration. The estimation was repeated till concurrent results were obtained.

Results.—The results obtained are given in Table VI below and are also represented in Fig. 4. It is to be noticed that the rate of accumulation of reducing sugars in the berries is rather slow during the first 4 weeks after setting. During this period the rate of respiration is correspondingly very high. This means evidently that the amount of sugars produced by the plant in its earlier stage is not very much in excess of what would be required for the respiration process. It is only after the metabolic activities come to a uniform rate that the accumulation of sugars occurs. At this time the amount of CO_2 given off by the berries also shows a decline and practically becomes constant after a few days more.

TABLE VI.

Showing percentage of reducing sugars expressed on dry weight of berries, throughout their life cycle.

Jaishi			*Tur*		
Date of estimation	Age of berries in days	Percentage of reducing sugars	Date of estimation	Age of berries in days	Percentage of reducing sugars
20th April 1929 .	2	·95	28th April 1929 .	5	1·24
23rd April 1929 .	10	3·65	3rd May 1929 .	15	4·39
27th April 1929 .	20	7·83	10th May 1929 .	19	7·62
8th May 1929 .	26	9·07	20th May 1929 .	29	9·00
16th May 1929 .	35	17·98	27th May 1929 .	36	15·22
23rd May 1929 .	40	23·06	3rd June 1929 .	40	54·55
30th May 1929 .	47	46·12	10th June 1929 .	50	88·41
6th June 1929 .	56	66·76	17th June 1929 .	55	94·74
13th June 1929 .	60	88·00			
20th June 1929 .	67	92·56			
26th June 1929 .	75	93·31			

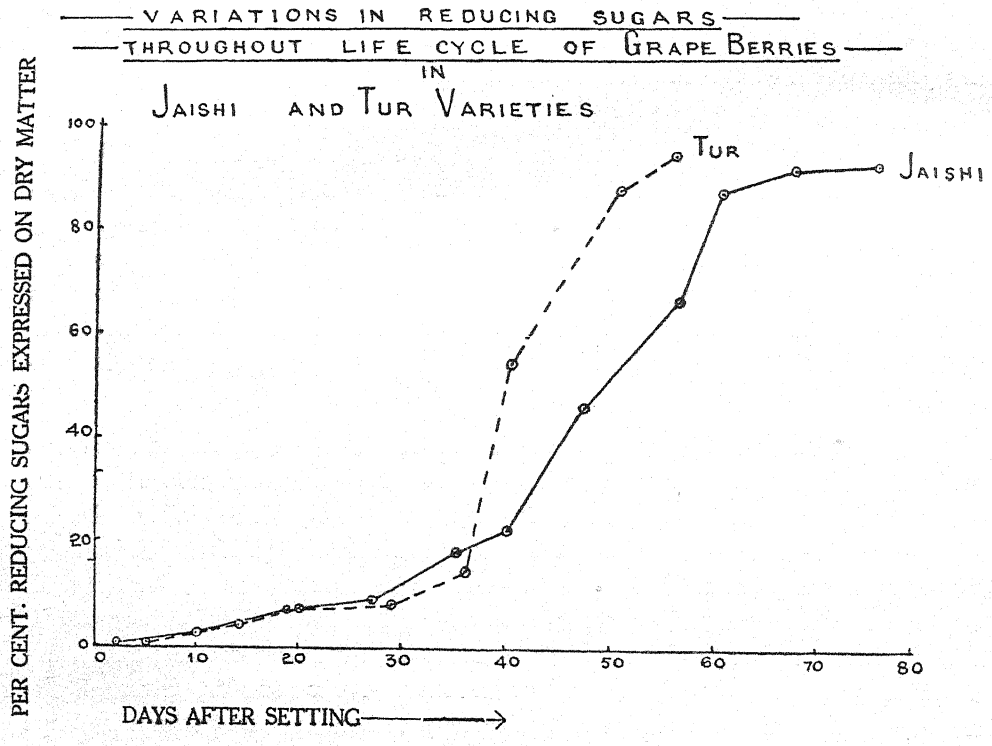

Fig. 4.

3. *Estimation of total titrable acids.*—Lewis [1927] has shown that the acids present in grapes consist mostly of tartaric and malic acids. The unclarified juice as prepared above was used for the estimation of these acids. This was done by titrating against $\frac{N}{10}$NaOH using phenolphthalein as indicator. Duplicate titrations being always carried out. The results obtained were expressed in terms of malic acid.

Results.—Table VII and Fig. 5 illustrate that the total titrable acids also increase during the first 4 weeks or so and then in parallel with the rise of reducing sugars, they begin to decline gradually. The decrease in the quantity of acids continues up to the end, when only about three per cent. of them are present on the 75th day in *jaishi* and 55th day in *tur*. The presence of such a small amount of acid in perfectly ripe berries obviously constitutes an advantage as far as its flavour and taste are concerned.

TABLE VII.

Showing the percentage of total titrable acids expressed in terms of malic acid on dry weight of berries.

Jaishi			*Tur*		
Date of estimation	Age of berries in days	Percentage of malic acid	Date of estimation	Age of berries in days	Percentage of malic acid
20th April 1929 .	2	14·46	28th April 1929 .	5	17·36
23rd April 1929 .	10	18·23	3rd May 1929 .	15	21·10
27th April 1929 .	20	27·60	10th May 1929 .	19	23·23
8th May 1929 .	26	30·0	20th May 1929 .	29	24·86
16th May 1929 .	35	36·98	27th May 1929 .	36	23·89
23rd May 1929 .	40	29·88	3rd June 1929 .	40	11·96
30th May 1929 .	47	16·84	10th June 1929 .	50	8·47
6th June 1929 .	56	10·90	17th June 1929 .	55	3·12
13th June 1929 .	60	6·46			
20th June 1929 .	67	4·35			
26th June 1929 .	75	3·27			

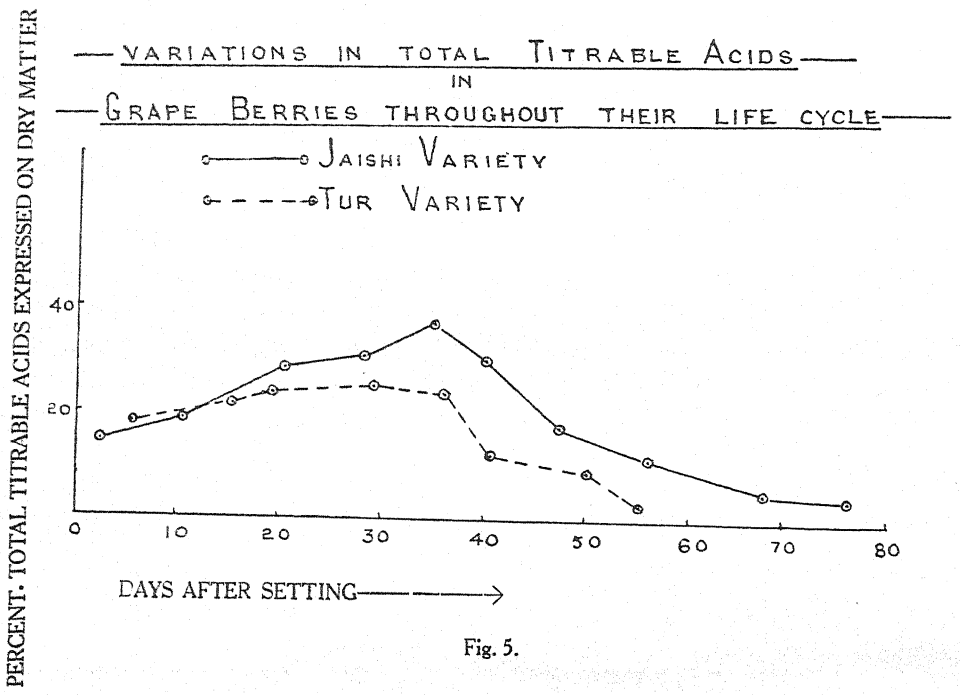

Fig. 5.

4. *Nitrogen.*—Nitrogen was estimated according to Kjeldahl's method . A weighed amount of berries generally 20—25 grams was transferred to Kjeldahl's flask and after the addition of 25 c.c. of concentrated H_2SO_4 and 10 grams of K_2SO_4 and a small crystal of $CuSO_4$, the whole was digested over a strong flame till the solution became quite transparent.

The contents on cooling were transferred to 500 c.c. flask and made up to the required volume. 50 c.c. of this solution were added to a distillation flask and strong soda solution added till the liquid became distinctly alkaline and ammonia liberated was received in 20 c.c. of $\frac{N}{10}$NaOH and thus the amount of H_2SO_4 used and consequently the amount of nitrogen present in the corresponding sample was calculated, from which the percentage of nitrogen in dry weight of berries was arrived at. In order to allow for the amount of nitrogen present in the different reagents a control was always run parallel to the experimental flask.

Results.—The determinations were made 4 times during the life cycle of berries in *jaishi* only. The results obtained are given in Table VIII which show that nitrogen falls down consistently up to the 47th day, while on 75th day there is a slight rise of which no satisfactoy explanation can be offered.

TABLE VIII.

Showing the percentage of nitrogen in grape berries expressed on dry weight at different times.

Variety	Date of estimation	Age of berries in days	Percentage of nitrogen
Jaishi	18th April 1929	5	2·41
	2nd May 1929	19	1·44
	30th May 1929	47	·536
	26th June 1929	75	1·11

5. *Water-insoluble Residue.*—Sugars and acids are the chief water soluble constituents in grape berries. A great deal of cellulose, proteins and other material insoluble in water are also present. The amount of these was determined by taking a known weight of berries and grinding thoroughly in a pestle-mortar till it was reduced to a fine pulp. This pulp was now repeatedly washed with distilled water to free it of all the soluble substances. Insoluble residue was dried in a steam oven to a constant weight.

Results.—Water-insoluble residue was found practically constant during the entire life cycle of the berries. It came to 4·73, 3·64 and 3·41 per cent. of the weight of fresh berries. It has been observed that total organic nitrogen shows a gradual decline. This would mean that this decline is rather restricted to the soluble portion of the nitrogen showing thereby that the metabolic processes during the growth and maturity of the berries make use of soluble and hence rapidly available nitrogenous substances.

6. *Specific gravity.*—The determination of specific gravity was made with the object of finding out the changes in the concentration of the juice during the ripening period of the berries. The juice was extracted as previously explained and filtered through 4 or 5 layers of fine muslin. Specific gravity was determined by actual weighing of the juice in a specific gravity bottle.

Results.—The analytical data obtained are shown in Table IX. The figures for specific gravity show a steady rise throughout the life-cycle, showing that the amount of soluble matter goes on increasing till the end. It is remarkable that

this increase runs almost parallel with the increase in reducing sugars, showing thereby that the amount of soluble material consists mainly of reducing sugars.

TABLE IX.

Showing the specific gravity of grape juice in Jaishi *variety.*

Date of estimation	Age of berries in days	Specific gravity of the juice
24th April 1929	12	1·0190
2nd May 1929	17	1·0192
9th May 1929	26	1·0198
16th May 1929	33	1·0239
23rd May 1929	40	1·0304
30th May 1929	47	1·0492
7th June 1929	54	1·0587
14th June 1929	61	1·0643
21st June 1929	68	1·0795
28th June 1929	75	1·0990

7. *Cellulose.*—This constituent was not determined directly but some idea can be obtained by subtracting from the figures for water-insoluble residue the corresponding amount of insoluble proteins as calculated on the nitrogen basis. The figures for nitrogen are arbitrarily multiplied by the factor 6·25 to get the proteins. The results are given below in Table X.

TABLE X.

Showing the percentage of cellulose in grape berries at different ages as calculated from water-insoluble residue and protein, etc.

Date of estimate.	Age of berriers in days	Percentage of nitrogen.	Percentage of total solids	Percentage of total proteins as calculated from nitrogen	Water-insoluble residue	Percentage of cellulose
18th April 1929	5	2·41	13·75	2·069	4·73	2·661
2nd May 1929	19	1·44	6·93	·619	3·29	2·671
30th May 1929	47	·536	10·47	·35	3·08	2·730
6th June 1929	75	1·115	20·0	1·394	3·41	2·016

It will be seen that the percentage of cellulose in the berries is unaffected by other changes that take place during the life-cycle of the fruit. The conclusion seems to throw some light on the cellulose constitution of the berries. The size of the berries increases and yet the amount of cellulose remains almost constant. Does this mean that the material comprising the cellulose is of an elastic nature, and in its distended form can serve the needs of the berries as well, as in the earlier stages of growth of the fruit? The question requires further investigation.

Discussion of the results.

As already remarked there is a distinct correlation between the respiratory process going on in the berries and the amount of sugars and acids present there.

A statistical study of correlation (1) between respiratory activity of the berries and reducing sugars in the case of *jaishi* shows that it is fairly significant and the co-efficient of correlation comes to $-\cdot52\pm\cdot14$. This evidently means that the increase in reducing sugars tends to lower the respiratory activity of the fruit and (2) between reducing sugars and total titrable acids indicates that the relationship is significant. Co-efficient of correlation in the case of *jaishi* is $-\cdot078\pm\cdot08$ and in the case of *tur* it is $-0\cdot92\pm\cdot03$. Respiration takes place to a great extent at the expense of soluble protein bodies. This means that the berries during their early period of growth make use of both sugars and proteins. That the amount of CO_2 given out by the berries after 4 or 5 weeks becomes almost constant points to the conclusion that henceforward the berries are functioning for the purpose of storing the products of photo-synthetic activity rather than meeting the demand involved during growth. The accumulation of sugars made after being saved in this way accounts for the economic importance of grapes.

The authors' thanks are due to Dr. Ramji Narain, Assistant to the Agricultural Chemist to Government, Punjab, for the help that he gave in carrying out the chemical part of the subject.

Summary.

1. Respiration rates of grape berries of *jaishi* and *tur* varieties were studied throughout their life-cycle. Experimental data show that the berries respired very actively during the early stages of their growth but the intensity of respiration slowed down as the berries advanced in age.

2. It appears that as ripening advances, there is an increase of sugars and a decline of respiration. Accumulation of sugars seems to retard respiratory activity, which is also affected by age.

3. Co-efficient of correlation between sugars and respiratory activity in the case of *jaishi* was worked out and was found to be significant. It came to $-\cdot52\pm\cdot14$.

4. Rate of respiration in detached grape bunches as well as those in *situ* has been found to be the same and decreased as the process of ripening progressed. The results obtained are in exact conformity with those obtained by Kidd, West and Briggs.

5. Study of the respiration of berries during night time has not shown any noticeable difference, when compared with the results obtained during day time. Lower temperature seems to be responsible for the slight fall in the respiratory activity at night.

6. Reducing sugers show a steady increase with the ripening process. The maxima in the curve for sugar corresponds with the complete maturation of the grape berries.

7. Total titrable acids go on increasing for about four or five weeks and afterwards they begin to fall. The maxima in acid curve coincides with the accumulation of sugars in much greater amounts than before.

8. Nitrogen : Nitrogenous contents show a straight decline till 47th day.

9. Water-insoluble residue remains practically constant throughout the life-cycle of the berries.

10. Specific gravity of the grape juice keeps a close pace with the increase of sugars.

11. Cellulose content of the berries remains stationary throughout, although several changes are taking place in other constituents.

12. Co-efficient of correlation between sugars and acids comes to $-0{\cdot}78 \pm 0{\cdot}08$ in the case of *jaishi* and $-0{\cdot}921 \pm {\cdot}03$ in the case of *lur*. It is found to be significant in both the cases.

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SOME OBSERVATIONS ON THE GROWTH OF *SESAMUM INDICUM*, D. C. IN DIFFERENT SOIL CONDITIONS WITH SPECIAL REFERENCE TO ROOT DEVELOPMENT.

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(With Plates LXVII and LXVIII.)

The importance of the relation of soil conditions to the development and distribution of root-systems is one of the chief considerations in the economic study of agricultural crops because it leads to an intelligent application to crop production.

In India, sesamum is grown in many different types of soil, from the poorest sandy soils to the richest clayey lands. It is but natural that the crop varies considerably in yield in the different soils. From the economic point of view, therefore, the different types of soil, which are most suitable for the full development of the crop, are worth investigating. With this idea two types of *Sesamum indicum*, Pusa Type 22 (early) and Pusa Type 29 (late) were sown in two series in different proportions of sand and clay. The plants were grown in large cylindrical containers made of wire-netting. These were lined inside thickly with plantain leaf-sheaths, and such pots were found to hold the soils very well. They were 15″ in diameter and 36″ deep.

The soils were prepared in the following proportions :—(*i*) clay*, (*ii*) $\frac{1}{4}$ sand+$\frac{3}{4}$ clay, (*iii*) $\frac{1}{2}$ sand+$\frac{1}{2}$ clay, (*iv*) $\frac{3}{4}$ sand+$\frac{1}{4}$ clay. Eight pots were used for each type thus allowing a duplicate set also running for observation. The soils were made uniformly moist, before filling in the containers, to provide the right condition for the germination of the seeds. As the sesamum crop is grown during the rains in Bihar very little irrigation was required; when the soil became dry an equal amount of water was applied to each pot.

The roots of the early series were washed two months, and those of the late three months, after sowing. They were washed out slowly with a "Knapsack

* Clay, as ordinary paddy field soil, Pusa.

Sprayer", preserving at the same time the natural spread of the roots with the aid of long needles which were thrust in to keep the roots in their natural position when the soil was being washed away.

The detailed observations made on the root and shoot were as follows :—

(A) Early Series (Type 22).

Soil: *Clay*.—The plant grew to a height of 54 cm. with three secondary branches, and formed 4 capsules. The main root was 10 cm. long and was about 8 mm. thick at the start and then tapered gradually. There were 10 secondary roots; most of these were situated within a few cms. from the soil surface. The secondary roots produced very thin tertiary roots and these were about 6 per 1 cm. length. The spread of the roots in general was not extensive. The colour of the roots was rather dark brown.

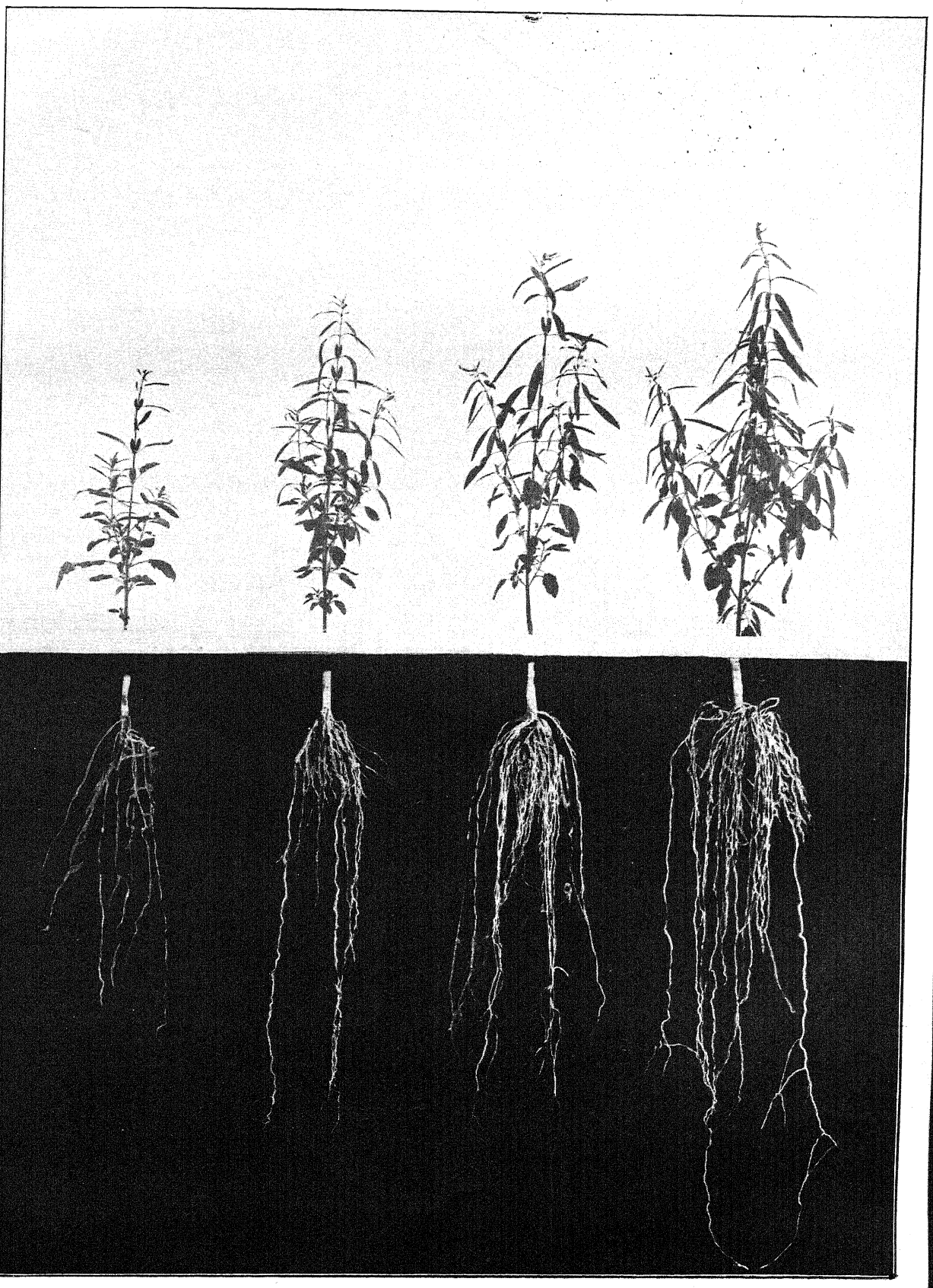
Soil: $\frac{1}{4}$ *sand*+$\frac{3}{4}$ *clay* .—The plant grew to a height of 62 cm. with 4 secondary branches and formed 24 capsules. The main root was 12 cm. long and it was about 9 mm. thick at start and then tapered gradually. There were 14 secondary roots, most of them being within 5 cm. from the soil surface. The secondary roots produced thin but long tertiary roots and these were about 10 per 1 cm. length. The spread of the roots in general was comparatively greater than in the previous case.

Soil: $\frac{1}{2}$ *sand*+$\frac{1}{2}$ *clay*.—The plant grew to a height of 72 cm. with 6 secondary branches and formed 128 capsules. The main root was 15 cm. long and it was about 10 mm. thick at start and then tapered gradually. There were 20 secondary roots, most of them being within 8 cm. from the soil surface. The secondary roots in this case were practically similar in proportions to those described above. The spread of the roots in general was greater than in the above cases.

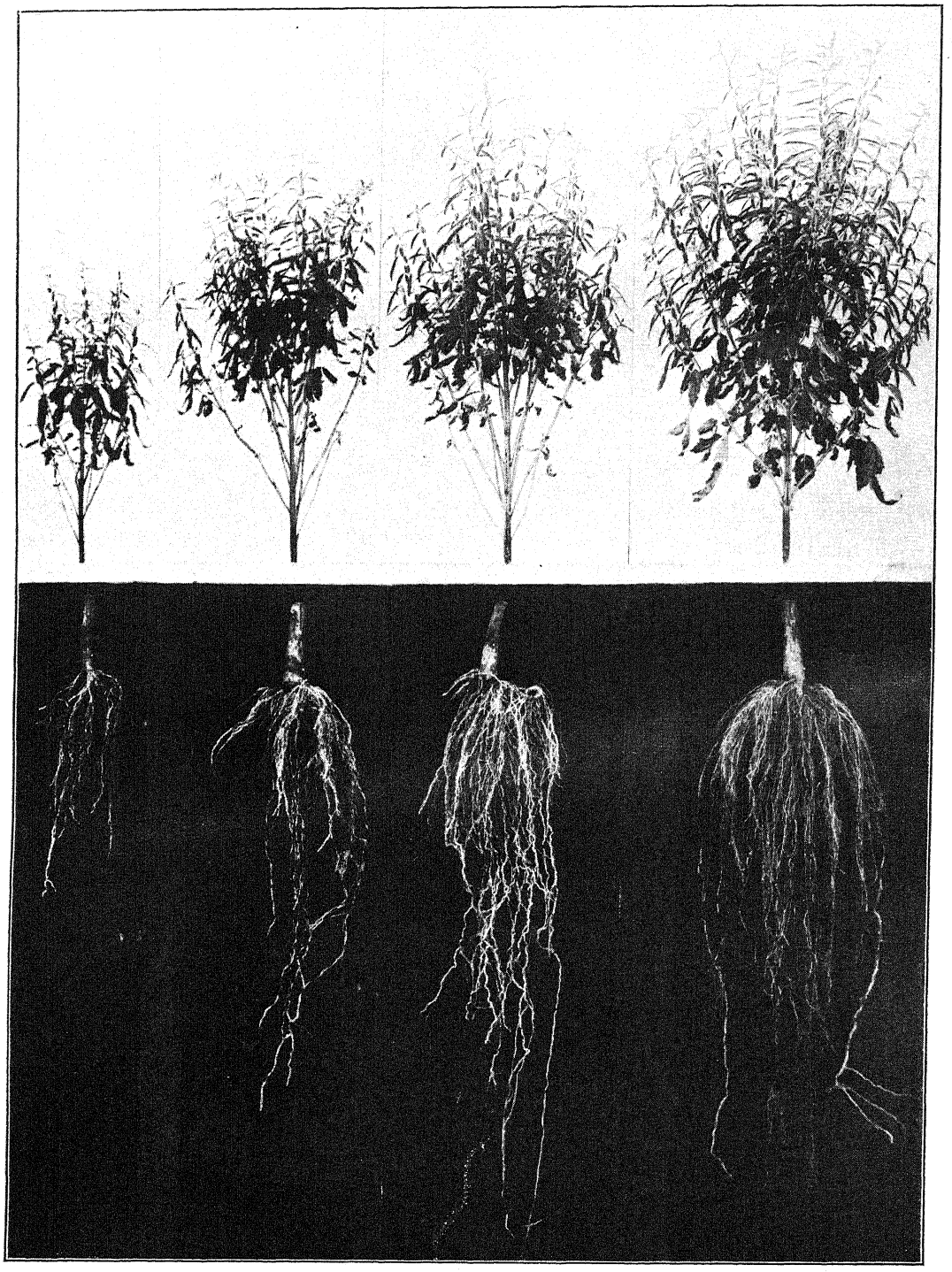
Soil: $\frac{3}{4}$ *sand*+$\frac{1}{4}$ *clay*.—The plant grew to a height of 82 cm. with 5 secondary branches and formed 150 capsules. The main root was 18 cm. long and 12 mm. thick at start and tapered gradually. There were over 35 secondary roots; practically all of them appeared within 12 cm. from the soil surface. The secondary roots produced enormous number of long tertiary roots and they were about 15 per 1 cm. length. The spread of the roots was the greatest of all in this group. The growth of the roots and the shoots of the early series are illustrated in Plate LXVII.

(B) Late Series (Type 29).

Soil: *clay*.—The plant grew to a height of 64 cm. with 14 secondary branches and formed 48 capsules. The main root was 20 cm. long and it was about 1·2 cm.



LATE SERIES_TYPE 29.



Clay. | $\frac{1}{4}$ Sand. $\frac{3}{4}$ Clay. | $\frac{1}{2}$ Sand. $\frac{1}{2}$ Clay. | $\frac{3}{4}$ Sand. $\frac{1}{4}$ Clay.

thick at the start and then tapered gradually. There were 14 secondary roots most of them being within 8 cm. from the soil surface. The secondary roots produced thin and fairly long tertiary roots and these were about 3 per 1 cm. length. The tertiary roots also produced very thin short roots. The general spread of the roots was not much. The colour of the roots was rather dark.

Soil : $\frac{1}{4}$ *sand* + $\frac{3}{4}$ *clay*.—The plant grew to a height of 84 cm. with 18 secondary branches and formed 98 capsules. The main root was 50 cm. long and it was about 1·5 cm. thick at start and then tapered gradually. There were 17 secondary roots most of them being situated within 10 cm. from the soil surface. The secondary roots produced long, thin, tertiary roots and these were about 4 per 1 cm. length. The tertiary roots were longer than those in the previous case and possessed thin short roots. The general spread of the roots was comparatively greater than in the above case.

Soil : $\frac{1}{2}$ *sand*+$\frac{1}{2}$ *clay*.—The plant grew to a height of 102 cm. with 20 secondary branches and formed 139 capsules. The main root was 55 cm. long and it was about 1·7 cm. thick at start and then tapered gradually. There were about 20 secondary roots, most of them being situated within 15 cm. from soil surface. The secondary roots produced thin, long, tertiary roots and they were about 6 per 1 cm. length. The tertiary roots produced thin long roots. The general spread of the roots was greater than that of the previous two cases.

Soil : $\frac{3}{4}$ *sand*+$\frac{1}{4}$ *clay*.—The plant grew to a height of 107 cm. with 22 secondary branches and formed 212 capsules. The main root was 60 cm. long and it was about 1·8 cm. thick at the start and then tapered gradually down to 15 cm. and was 5 mm. thick, down the entire length. There were more than 35 secondary roots, most of them being situated within 20 cm. from the soil surface. The secondary roots produced very long tertiary roots and they were about 10 per 1 cm. length. The tertiary roots also produced thin roots. The general spread of the root was the greatest of all in this group. The growth of the roots and the shoots of the late series are illustratad in Plate LXVIII.

From these observations and the accompanying photographs it is clear that as we proceed from the pot with clayey soil to the one with sandy soil, there is a marked increase of vigour which results in greater height, greater number of capsules, longer and thicker main root with accordingly well defined secondary and tertiary roots. The colour of the roots in the clayey soils is darker than the roots from the sandy soils. There is a definite correlation in growth and vigour between the root and the shoot. It is clear that the roots show their maximum development and distribution in the sandy soils. The growth in the soil with the largest proportion of sand is much better than in the other soils and hence we infer that sesamum prefers a light sandy soil with the necessary moisture for its maximum development.

SELECTED ARTICLE

THE SHEDDING OF NODULES BY BEANS.*

BY

J. K. WILSON.†

[Reprinted from the *Journal of the American Society of Agronomy*, Vol. 23, No. 8, August, 1931.]

Under uniform conditions nodules on leguminous plants probably remain as long as they are of any service to the plant. If growth conditions can accommodate a greater number, new nodules may develop. If adverse growth conditions are encountered after a period of favourable growth, nodules may be shed. Experiments have shown that with an increase in moisture there is an accompanying increase in nodulation until the plant has reached an equilibrium at this new moisture content with those symbiotic conditions that bring about nodulation. Little is known, however, about what happens to a portion or all of the nodules that have developed under the best nodulating conditions when the plant encounters less favourable growth circumstances. It would seem logical that if an increase in moisture causes a plant to develop more nodules that the reverse condition should cause it to shed nodules. The observations recorded in this paper are of interest in this connection.

TECHNIC

The effect of a reduction in moisture content from that which was present when nodulation occurred was measured by observing the number and physical condition of nodules that remained on plants after they were subjected to various degrees of desiccation. The exact procedure of how such information was obtained is given in the following paragraphs.

Dunkirk silty clay loam was taken from a field where beans were growing. This was placed on a large canvas and uniformly mixed. Equal weights of the moist soil were put in one-half gallon crocks. The total weight was taken of each crock with the soil in it in order that moisture conditions could be controlled. A sample was also used for moisture determination. Calculations showed there were in each crock 1,860 grams of dry soil. With these facts at hand, it was possible to adjust the moisture content in any crock to any desired percentage.

In order to have uniform conditions for nodule formation, the soil in each crock was not only thoroughly inoculated with a water suspension of the proper

* Contribution from the Dept. of Agronomy, Cornell University, Ithaca, N. Y. Received for publication February 18, 1931.

† Professor of Soil Technology.

organism, but also was maintained at 20 per cent. moisture. The crocks were kept standing in running water so that temperature conditions for all would be alike. Frequent weighings, sometimes twice daily, and the addition of distilled water kept the moisture content reasonably uniform.

Red kidney beans were planted on July 22, about 10 to 12 for each crock. On August 14, inspection showed plants to be well-nodulated, giving an average of at least 30 nodules to the plant. At this period desiccation was begun. The crocks were divided into groups of four and the moisture spontaneously reduced to the following percentages: 20, 15, 12·5, 10 and 8. After the moisture reached the desired percentage it was maintained at this content for one day and then brought back to the original 20 per cent.

Shedding observations

Observations were made on September 9. The plants were just beginning to bloom. Those in crocks where the moisture had been reduced to 10 and 8 per cent. were showing the effects of such a treatment. The lower leaves were beginning to turn yellow and in some cases to fall off. After the plant roots were freed from soil by gently washing them with a stream of water they were examined. The physical condition and number of nodules that remained on plant roots which had been desiccated to the varying percentages of moisture were observed. The data, together with other notes that seem desirable, are shown in Table I.

Table I.

Effect of moisture reduction from that which was present when nodulation occurred on the number and the physical condition of the nodules on red kidney beans.

Percentage moisture reduced to	Number of nodules remaining on each plant	Affected nodules		Condition of affected nodules
		Number	Per cent.	
20*	35, 13, 53, 14, 78, 43, 54, 25, 61, 90, 51, 84, 58, 72, 106, 113, 86, 101, 101, 112, 110.	None	None	
15	75, 64, 89, 82, 130, 32, 39, 18, 28, 35, 23, 60, 48, 57, 72, 50, 84, 44, 42, 38.	11, 20, 11 . .	0·04	Soft and float on water.
12·5	48, 47, 72, 46, 80, 52, 112, 51, 49, 43, 85, 50, 89, 54, 36.	26, 26, 28, 15, 46, 22, 35, 15, 19, 18, 44, 35, 50, 33, 20.	36·00	Soft and float on water. Some hollow, some very brown.

* Present when nodulation occurred.

TABLE I—*contd.*

Percentage moisture reduced to	Number of nodules remaining on each plant	Affected nodules		Condition of affected nodules
		Number	Per cent.	
10	35, 55, 66, 57, 52, 34, 25, 52, 109, 44, 29, 24, 53, 46, 70, 34, 70, 30, 70, 9, 17.	0, 0, 0, 20, 14, 15, 8, 0, 18, 9, 0, 0, 13, 0, 0, 0, 17, 16, 24, 6, 12.	15·00	Soft and float on water; none hollow; 24 dislodged from plant roots and dark.
8	33, 44, 79, 57, 21, 50, 103, 50, 41, 30, 41, 64, 104, 65, 11, 39, 55, 23, 89, 29, 48, 38, 19, 28.	Not determinable.	..	About 50 floaters; some badly decayed; others unhealthy but no visible signs of decay.

The records are typical of several such tests. They indicate clearly that a reduction in moisture of a few per cent. for 24 hours from that which was present when nodulation occurred resulted in a shedding of nodules. A drop in moisture from 20 to 12·5 per cent. destructively affected 432 of 1,346 nodules. This was over 36 per cent. Individual plants showed as high as 57 per cent. of the nodules to be affected. Some of the affected nodules were light enough to float on water, some were soft, while all that was left of others was an empty hull. The latter were characterized by a brown or dark color. Many of those that were not visibly affected were undoubtedly less vigorous and of reduced value to the plant.

Many of the nodules recorded in the table as remaining on plants at harvest time were in reality some that had developed between the end of the desiccation period and harvest time. This was judged partly from the small size and fresh appearance which they exhibited and partly from the average number of nodules on plants when desiccation was started in comparison with those present at harvest time on plants constantly kept at a uniform moisture content. Shedding of nodules occurred more readily on the small and fibrous roots than on the tap root or from locations near the tap root. The mechanism by which the nodules were shed was not observed. There was no evidence that the contraction of the soil during desiccation took part in the process. Most of the nodules affected were still in contact with the root, and decay seemed to begin on the inside of the nodule. In a similar experiment a drop in moisture from 25 to 20 per cent. also caused a similar shedding of nodules.

It required a considerably longer time to desiccate the soil to 10 or 8 per cent. moisture than to 15 or 12·5 per cent. This means that those plants which grew

in soils desiccated to 10 or 8 per cent. had a shorter time for the decay of affected nodules, before being examined than did those plants which grew in soil desiccated to 15 and 12·5 per cent. moisture. This made it difficult to determine how many of the nodules were affected and may account for the observed condition of nodules on those plants from crocks where the moisture was reduced to 10 and 8 per cent.

Discussion

These results offer a reasonable explanation for the failure of numerous investigators to obtain beneficial results from artificial cultures, particularly on beans, and suggest why such cultures may sometimes reduce bean-yields. Once a plant has formed numerous nodules, as is often the case in wet soil in early spring, and subsequently encounters a dry period before maturity, it may shed many nodules. When the moisture is again increased new infections occur. This process of nodulation and shedding of nodules, in various degrees of completeness, may happen several times during the life of the plant. The effect of such recurring nodulation and its resulting intermittent service to the plant may stunt it so badly that final growth may be considerably less. Early growth in the presence of high moisture with accompanying stimulated nodule production brought about by the use of artificial cultures may produce a plant that canno readily adjust itself to drastic moisture changes which may often occur before plant maturity.

These findings also aid in the interpretation of many conflicting data, particularly those relating to nodular counts on plants at or near blooming time. Such data are without question subject to considerable experimental error and should not be given too much credence unless one knows the moisture conditions to which the plants have been subjected before the observations are made.

Although the observations presented were made on young bean plants, there seems to be no reason why the effect of desiccation on nodules should not apply to many other legumes.

Conclusion

Plants were grown in soil whose moisture content was controlled. After nodulation had occurred the moisture content of the soil was reduced to definite values for 24 hours and the effect on the existing nodules observed. The outstanding observations are listed below.

A reduction of soil moisture from 20 to 12·5 per cent. caused bean roots to shed on the average about 36 per cent. of their nodules. Some individual plants showed 57 per cent. of their nodules to be destructively affected by this drop in moisture. Shedding occurred more freely on small and fibrous roots than on larger roots.

ABSTRACTS

Fauna of Lahore. 1-Butterflies of Lahore. D. R. PURI. *Bull. Dept. Zool. Punjab University.* Vol. I, pp. 1—61, [Coloured Plates I—IV, bibliography 94] April 1931.

A systematic account of 57 species of butterflies collected from Lahore, mainly during the summer of 1925, is given. Keys to genera and species have been added. A number of the species mentioned are of economic importance as pests of crops. [M. A. H.]

Agricultural Meteorology of Indo-China [trans. title]. P. CARTON (*Agr. Prat. Pays Chauds, n. ser., 2 (1931), No. 9, pp. 199—209, figs. 4*). [Extracted from the Experiment Station Record, U. S. A. Department of Agriculture, Vol. 64, No. 9, June 1931].

The Bureau of Climatology and Agricultural Meteorology, organized in 1926 in the Meteorological Service of Indo-China, is described. The bureau receives data from 26 meteorological stations, 65 climatological stations, and 354 rainfall stations. Its work is confined to studies in climatology and agricultural ecology, in which it has the collaboration of specialists in coffee, tea, rubber, sugarcane, cinchona, and other economic plants, and of directors of experiment stations and plantation owners, as well as of the agricultural hydraulic service especially in the study of evaporation and winds.

A Study of Factors Influencing Inoculation Experiments with Azotobacter P. L. GAINEY. (*Kansas Sta. Tech. Bul.*, 26 (1930), pp. 66). [Extracted from the Experiment Station Record U. S. A. Dept. Agri., Vol. 64, No. 9, June 1931].

The natural distribution of Azotobacter was found 'very closely associated with, if not dependent upon, the absolute reaction of the soil'. It was further observed that when bacteria of this genus are introduced into cultivated acid soils with a pH of less than 6·0 they soon perish, the rapidity of this disappearance depending upon the degree of acidity.

'The addition of basic substances such as $CaCO_3$, $MgCO_3$ or neutral of basic soil in sufficient quantities to reduce the H^+ concentration to less than 10^{-6} will render acid soils a fit pabulum for the existence of Azotobacter. The addition of sufficient quantities of acid to a soil containing Azotobacter to maintain permanently a H^+ concentration greater than 1×10^{-6} in the soil solution will result in the disappearance of Azotobacter therefrom. The maximum H^+ concentration in the soil solution compatible with the existence therein of an active Azotobacter flora is very near 1×10^{-6}. The major factor controlling the existence of Azotobacter in soils, at least as so far determined, is the hydrogen-ion concentration of the soil solution, the hydrogen-ions apparently acting directly as a toxic agent, though there is a possibility that they may act indirectly by affecting some other soil constituent.'

Midrib Forking in Sorghum.—G. N. RANGASWAMI AYYANGAR and P. SUBRAMANYAM. *Madras Agri. Jour.*, Vol. XVIII, (1930), No. 10, pp. 526—529; 1 fig; 6 tabs.

The midribs of certain sorghum plants were found to bifurcate. The forking varied with the number of plants in which it is manifested in each line, the number of leaves in which the forking appeared and in the intensity of forking. The number of such plants varied from an odd plant to half the population. The behaviour in inheritance of the character was pursued. Midrib dichotomy is regarded as an ancestral feature. It may also have a bearing on the Ranalian origin of the Monocotyledons. [G. N. R.]

Polyembryony in *Elusine Coracana* (Gaertn), *Ragi*. G. N. RANGASWAMI AYYANGAR and N. KRISHNASWAMI. *Madras Agri. Jour.*, Volume XVIII (1930), No. 12, pages 593-595.

The occurrence of Polyembryony in *Ragi* has been recorded for the first time. True Polyembryony is rather rare among cereals. A microscopical examination was made, but from the nature of the material it was not possible to determine the manner of origin of the second embryo.

Current theories of Polyembryony are shortly reviewed and the view that, Polyembryony is an ancestral feature, reminiscent of the Gymnosperms is supported. The role of hybridity is considered to be that of bringing out the reversion by altering the normal tenor of the plant's life.

Sixteen references to literature have been cited. [G. N. R.]

Sorghum-studies in sowing depths. G. N. RANGASWAMI AYYANGAR and K. KUNHI KRISHNAN NAMBIYAR. *Madras Agri. Jour.*, Volume XIX (1931), No. 5, 3 figs.

Sowing depth in sorghum varies with soil and moisture conditions. Successful germination is due to the combined effort of mesocotyl and coleoptile. This combined length is a varietal character and is elastic within limits. Appreciable differences are noticeable within strains. This aspect of a strain will have to be remembered in its evolution. [G. N. R.]

A study of the Chemistry of Indian Buffalo milk Casein. R. B. GODE and D. L. SAHASRABUDDHE. *Jour. Central Bureau Ani. Husbandry and Dairying in India*, Volume III, part I, April 1929 and part II, July 1929.

After discussing the various methods of preparing fat-free and ash-free casein the most suitable method found by actual experiments is described. The ultimate analysis of buffalo casein done is compared with English cow casein. The former contains more of carbon and less of nitrogen than the latter.

The results obtained in the estimation of the di-amino acids in the hydrolytic products of buffalo casein by hydrochloric acid show that amid nitrogen is extremely low when compared with that in the hydrolytic products of cow casein, humin is much higher than in cow casein, corresponding to the decrease in the amid nitrogen there is an increase in the non-amino nitrogen, the quantity of cystine is negligible in buffalo casein while arginine, histidine and lysine and amino acids are practically the same in both the caseins. The action of pepsin and trypsin on buffalo casein shows that this casein is more difficult to digest than the cow casein. [D. L. S.]

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